CARDIOPULMONARY ANALYSIS OF HABITUATION TO SIMULATED KAYAK ERGOMETRY

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(ABSTRACT)

All forms of exercise equipment require a period of habituation in which individuals adapt to the novel movement required in operating the device and reach a point of physiological stability. During this adaptation period, physiological variables which indicate cardiopulmonary demand typically will change. In general, such changes are expected with devices that require complex movements. The influence of this habituation on physical performance is vital for establishing research methodology in which precise control of power output is necessary.

The StairMaster® corporation has recently introduced the CrossRobics™ 2650UE (2650UE), an ergometer which simulates the kayak stroke pattern. In contrast to bicycle and arm crank ergometers, with which the user follows a set motion, the 2650UE allows the user to adopt a variety of movement patterns. To determine responses during habituation to the 2650UE, 14 female and 12 male subjects (18-32 years of age) were monitored during their first four exercise trials. Each session was 10 min long at a constant load of 0.36 watts/kg ± 0.02SD and 0.55 watt/kg ±0.02SD for female and male subjects, respectively.

Significant differences ($p<0.001$) were found for VO_2, $\dot{V}O_2$, $\dot{V}_E$, HR, and RPE across the four trials, with decreases of 6.3% to 9.5% from the mean values in trial 1 to trial 2. *Post hoc* analysis indicates that a minimum of two 10 min practice trials are required for measures of oxygen consumption to stabilize, whereas one 10 min practice trial is required for measures of $\dot{V}_E$, HR, and RPE to stabilize.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

INTRODUCTION

The CrossRobics™ 2650UE (2650UE) recently has been introduced by the StairMaster® corporation for the exercise industry. This equipment differs from conventional exercise equipment in that it is designed to provide the user with arm and torso training that combines both a strength and endurance stimulus within the same exercise bout. Unlike traditional ergometers, such as the treadmill and cycle, the 2650UE simulates a kayaking movement, which involves the muscles of the arms and torso. A substantial amount of research has gone into ergometry involving the arms and legs, but very few studies have involved ergometry that involves extensive use of the torso. One other ergometer which is based upon a kayaking motion has been developed for use in training kayakers during the off season, but there have been no published studies on the exercise habituation time required to reach a proficient training level.

There is a wide variety of exercise equipment available on the market today and people are interested in the benefits offered by this equipment. Human performance laboratories offer one avenue for the testing of the physiological responses expected from the use of exercise equipment. In order to obtain meaningful data from the testing of equipment, proper methodology must be established and followed. The common forms of exercise ergometers found in human performance laboratories are the treadmill, the cycle ergometer, and the arm ergometer. For each of these types of ergometers, a period of habituation is required to familiarize novice subjects with the motion involved and to allow physiological adaptations to reach a minimum as extraneous movements and tensions are eliminated. Even with common modes of exercise, such as walking, running and cycling, there is a period of habituation required; this includes subjects that train in these modes of exercise outside of the laboratory environment. For the 2650UE, the motor pattern involved is not a common form of exercise, and there are many variations in the biomechanics of a kayak stroke (Plagenhoef, 1979), such as the angle of incline of the "paddle" and the path followed by the joint centers. In comparison to the traditional arm-crank ergometer, where the joint path followed by the wrist is fixed to the path of the crank arm, the 2650UE allows the subject not only to vary the path followed by the wrist in terms of radial distances from a central axis but also to vary the position of this central axis and additionally to vary the path away from the vertical plane. The ability of the subject to vary stroke patterns while maintaining a constant work output to the ergometer can be compared to the variability involved in treadmill ergometry in which subjects can vary stride patterns. We do not know the length of habituation required for physiological values to stabilize across trials on the 2650UE, and we do not know by how much these values may exceed the values for work after habituation. Through measurement of the habituation period we can begin to quantify the adaptation response which will allow the researcher to design appropriate protocols for experimentation. This also will allow the fitness professional to make recommendations for the initial use of the equipment.

In the past, researchers have measured habituation to exercise equipment in various ways. Chandler et al (1995) as well as Wall and Charteris (1980, 1981) have quantified the movement, position and angles of joints and limbs to establish the point at which these variables stabilize over time, while Erickson (1946), Shephard (1966, 1969), and Sparrow (1987, 1994) have looked at variations in heart rate and oxygen consumption. These methods follow an underlying premise that subjects tend to become stable and more efficient over exposure to exercise on the equipment.

STATEMENT OF THE PROBLEM

Before subjects become habituated they will be exerting more effort than is required to maintain the workload setting on the ergometer. This extra effort results from superfluous movements of the body and limbs, as well as the development of muscular tensions which are not contributing to work output as measured by the ergometer. Inefficient muscular contractions place a demand on the cardiorespiratory system that results in increased heart rates, levels of oxygen consumption, and pulmonary demand. Additionally, perceived exertion should reflect these increased demands. As subjects become habituated, inefficient responses should diminish, resulting in reductions in both variability and physiological demand. Hypothetically, as extraneous muscular contractions are minimized, overall efficiency should increase across trials and eventually reach a point of stability. Habituation is achieved at this point of stability.

SIGNIFICANCE OF THE STUDY

In order to efficiently utilize laboratory resources while maintaining the integrity of data collection, it is essential to know the length of the habituation period for the exercise equipment on which tests will be run. For example, data collected during the habituation period will erroneously represent subject performance at the task. With this type of error entered into a series of data points, the changes associated with habituation could be mistakenly attributed to treatments across trials. Without evidence of the habituation period associated with a particular testing mode, the experimenter is confronted with uncertainty regarding the effects of any experimental intervention that may be studied via the testing mode. In terms of efficient use of laboratory resources, the time provided for habituation to equipment can quickly multiply, especially for experiments involving large numbers of subjects.

All forms of exercise equipment require a period of habituation or neuromuscular learning in which individuals adapt to the novel movement required in operating the device. During this adaptation period, physiological variables which indicate cardiopulmonary and metabolic demand typically will change. In general, such changes are most marked with devices that require complex movements. As these physiological variables fluctuate, the load settings on the equipment will not accurately or consistently reflect the biological demand levels that are desired by the individual. In a fitness center setting, if the responses of a first time user to an ergometer are significantly different than are expected on subsequent trials, then these responses should be related to clients. The influence of learning curves on physical performance also is vital for establishing research methodology in which precise control of power output is necessary. In many instances, the ability to precisely control power levels is essential in experiments where the goal is to study incremental loading effects on cardiopulmonary and metabolic functions. Variations in heart rate, cardiopulmonary response, and perceived exertion over trials were used as the markers of habituation. These markers were chosen because they are variables which are commonly used to evaluate performance, so it is essential to know when they become stable over trials.

The purpose of this study was to measure and compare oxygen uptake, cardiorespiratory, and perceptual responses during a series of constant load exercise tests on the StairMaster® CrossRobics™ 2650UE ergometer in healthy college-aged males and females, to determine the habituation period associated with these responses.

RESEARCH HYPOTHESES

H_{01}: There is no difference in relative oxygen consumption, VO_2 (ml·kg^{-1}), summed over the first six minutes of exercise, at a constant submaximal workload, on the StairMaster® 2650UE, across a subject's first four trials.

H_{02}: There is no difference in the mean rate of oxygen consumption, $\dot{V}O_2$ (ml·kg^{-1}·min^{-1}), over minutes seven through ten, at a constant submaximal workload, on the StairMaster® 2650UE, across a subject's first four trials.

H_{03}: There is no difference in mean heart rate (bt·min^{-1}) over minutes seven through ten, at a constant submaximal workload, on the StairMaster® 2650UE, across a subject's first four trials.

H_{04}: There is no difference in mean ventilation, $\dot{V}_E$ ($l \cdot min^{-1}$), over minutes seven through ten, at a constant submaximal workload, on the StairMaster® 2650UE, across a subject's first four trials.

H_{05}: There is no difference in rate of perceived exertion at minute nine, at a constant submaximal workload, on the StairMaster® 2650UE, across a subject's first four trials.

H_{06}: There is no difference in mean respiratory exchange ratio over the minutes seven through ten, at a constant submaximal workload, on the StairMaster® 2650UE, across a subject's first four trials.

DELIMITATIONS

The following delimitations were inherent in the design of this investigation:

1. The study was confined to healthy males and females, 18 to 32 years of age, recruited from the Blacksburg area.
2. The independent variables were confined to the first four 10 minute submaximal constant load exercise sessions on the 2650UE.
3. The dependent variables were confined to VO_2 over minutes one through six, mean values over minutes seven through ten for $\dot{V}O_2$, HR, $\dot{V}_E$, RER, and RPE in the ninth minute of exercise during each of the four submaximal constant load exercise sessions.

LIMITATIONS

The limitations of the study were:

1. Subjects were recruited in a non-random manner, so the findings of the study may be specific only to the sample of subjects in this study.
2. Measurements were taken over four constant load exercise trials which may not represent the total habituation response.

BASIC ASSUMPTIONS

1. The MedGraphics® CPX/D metabolic cart was properly calibrated before each test.
2. ECG tracings were accurately recorded and measured.
3. Subjects responded honestly when asked to rate their perceived exertion.
4. Oxygen consumption, VO_2 ($ml \cdot kg^{-1}$) over the first six minutes of exercise at a constant submaximal workload is a response variable that is stable from day-to-day and indicates habituation to the exercise ergometer.
5. Mean values for $\dot{V}O_2$, HR, $\dot{V}_E$, and RER over minutes seven through ten of exercise at a constant submaximal workload are response variables that are stable from day-to-day and indicate habituation to the exercise ergometer.
6. The rate of perceived exertion in the ninth minute of exercise at a constant submaximal workload is a response variable that is stable from day-to-day and indicates habituation to the exercise ergometer.

7. Subjects put forth a consistent effort during the exercise trials.

8. Subjects put forth maximum effort during the $\dot{V}O_{2peak}$ test.

9. Subjects complied with pre-test instructions.

DEFINITIONS AND SYMBOLS

The following definitions and symbols are essential to the understanding of this study:

Ergometer - a device used for measuring the work output of a group of muscles

Habituation - decrease in responsiveness upon repeated exposure to a stimulus

Heart rate (HR) - the frequency of contractions of the heart

MET - unit of measurement that represents a multiple of resting metabolic rate

Rating of perceived exertion (RPE) - subjective numerical ratings assigned to the perceived effort of exercise

Respiratory exchange ratio (RER) - the ratio of carbon dioxide produced to oxygen consumed

Ventilation ($\dot{V}_E$) - the volume of gas expired from the lungs per minute

VO_2 - the volume of oxygen consumed; measured as the difference between the volumes of inspired and expired oxygen

$\dot{V}O_2$ - the volume of oxygen consumed (VO_2) per unit time

CHAPTER II

LITERATURE REVIEW

INTRODUCTION

Habituation to exercise with various exercise devices can be defined in several ways from measures of mechanical efficiency or stability to stability of oxygen consumption over trials. For this study several variables that represent cardiorespiratory demand, pulmonary demand, and perceived demand were used to evaluate habituation. Habituation for each of these variables is defined as the point at which further practice will not produce significant reductions in their respective values.

The first section of this chapter reviews the concept of habituation and how other researchers have dealt with it in the past. The second section discusses exercise economy and how it is related to habituation. Additionally, this section covers aspects of exercise economy that are common among various modes of exercise and are similar to exercise on the CrossRobics™ 2650UE. The third section discusses oxygen consumption and its relation to total work, and the final section addresses the similarities and differences between upper and lower body exercise.

HABITUATION

As Schöner (1992) points out, learning has been defined and experimentally tested a variety of ways in several disciplines. One of the methods of experimentally testing learning is through habituation, which we have used in the present study. Habituation is "the decrease in the strength of the behavioral reaction to a repeatedly presented stimulus," as defined by Pinel (1990). In our study, the behavioral reactions are manifest in the physiological responses to the stimulus of constant load exercise. Various physiological responses to exercise have been chosen as markers of habituation by several previous researchers.

Past Research

Shephard (1966) has noted that habituation to an unaccustomed form of exercise may improve performance through the reduction of psychically induced tachycardia and hyperventilation. He also points out that excessive ventilation is in part due to cerebral cortical influences on respiration. To evaluate ventilatory and cardiac responses to short training programs on a bicycle ergometer, 73 male subjects, ages 18-40, were divided into groups and tested as they followed various programs. Sixteen subjects were tested with 5 minute maximal sessions over the course of 5 days, 55 subjects were tested at constant submaximal workloads of 140 watts three times a day for either 5 or 10 days, and 2 subjects were tested at a workload of 92 watts three times a day for 5 days. Ventilation was measured in thirty second intervals during exercise and recovery for the first test each day, heart rate was measured before each test and during recovery, and oxygen consumption was measured during the last minute of exercise on days 1 and 5. The results of these experiments revealed that ventilation during both exercise and recovery decreases significantly ($p<0.001$) over the course of five days, with the majority of the decrease occurring from day 1 to day 2, and there was also a significant decrease in recovery heart rate from day 1 to day 2. These changes were seen in both trained and untrained subjects, and previous road cycling experience had no effect on the responses measured in this experiment. Over submaximal exercise trials, Shephard was able to detect a reduction in ventilation from levels that initially exceeded the metabolic demand. This reduction from excess levels of ventilation was attributed to a habituation to the exercise. Additionally, subjects demonstrated improvements in perceptual and respiratory measures, which Shephard also attributed to habituation.

Davies et al. (1968) studied the rate of habituation to exercise on a bicycle ergometer. Heart rate and oxygen consumption, $\dot{V}O_2$, were measured for 6 male subjects (17-22 years old) during standardized continuous maximal and submaximal effort. Heart rate was shown to decline significantly over the first three trials at any given submaximal oxygen uptake. Subjects were tested 16 times over the course of three weeks and after the first three tests no significant differences were seen. Oxygen consumption at fixed workloads was also evaluated and was not shown to change across trials. This constant oxygen consumption at fixed workloads on a bicycle ergometer has been attributed to the fact that the learning associated with bicycle ergometry is fairly small (Shephard, 1966). From this study, Davies et al. concluded that a minimum of three preliminary tests are necessary before the collection of reliable bicycle ergometry data.

Shephard (1969) conducted an array of tests in which habituation to exercise was evaluated across several parameters. It has been postulated that habituation decreases with increasing exercise intensities, so one aspect of Shephard's study was to evaluate habituation across various submaximal workloads. Twenty-four male subjects, mean age

26 years, were tested at four submaximal workloads on three modes of exercise (bicycle ergometer, step-test, and treadmill). Subjects were tested submaximally on each mode twice a week on weeks 1, 2 and 5 with maximal tests occurring during weeks 3 and 4. Submaximal tests consisted of five minutes of exercise at each workload with 7 to 10 minutes of rest between workloads. Heart rate was measured from an electrocardiogram of the last 15 seconds of each minute and expired gas was collected during the last minute of exercise at each load. These data reveal significant ($p<0.001$) decreases in the ratio of heart rate to oxygen consumption. The greatest effect of habituation was seen at intermediate workloads where heart rate ranged from 120 to 150 $bt \cdot min^{-1}$ for bicycle ergometer and step-test exercise, while habituation effects for treadmill exercise were equal at both intermediate and high workloads. The habituation effects occurred from day 1 to day 5.

A second objective of Shephard's (1969) experiments was to evaluate the effect of training on habituation. Two step-tests were performed on 27 male subjects before and after a course of training. Twelve subjects, mean age 36 years, participated in a program of calisthenics, running, and swimming for 6 to 15 weeks, while the remaining fifteen subjects, mean age 31 years, trained on the laboratory treadmill over the course of 4 to 6 weeks. Oxygen consumption and heart rate were evaluated at a moderate work rate, where heart rates ranged from 120 to 160 $bt \cdot min^{-1}$, so that the maximum habituation effect could be seen. The data reveal that both groups improved their maximum oxygen consumption over the course of training, and that some habituation to step-testing occurred both before and after the course of training. This demonstrates that some loss of habituation to step-testing occurs after four weeks. A greater habituation to step-testing was seen after the course of training which indicates that after an initial habituation, subsequent habituations may occur more rapidly.

Shaw et al. (1996) compared the responses of two groups of elderly subjects on a maximal cycle ergometer stress test. One group was oriented with a submaximal progressive exercise test under similar conditions as the maximal test, while the other group served as a non-oriented control. The results of the stress test revealed significant differences in heart rate, systolic blood pressure, and oxygen uptake ($\dot{V}O_2$) at submaximal workloads. Differences in maximal performance were small, following the decrease in habituation effects with increasing work as reported by other researchers (Williams and Singer, 1975).

Sparrow et al. (1987, 1994) have demonstrated that metabolic energy expenditure decreases as a function of practice. In their experiments, crawling on a treadmill was used as a novel form of activity. Five male subjects, mean age 24, were used in the first experiment in which one 3 minute trial was performed on alternate days for a total of 10 trials. In their second experiment, 3 male subjects, mean age 29 years, performed two 3 minute trials per session for 8 sessions over a 6 week period. Oxygen consumption and heart rate data were collected in addition to biomechanical measures of gait, such as stride length and swing duration. In the first study, decreases in caloric cost were shown up to days five and six of practice. Overall decreases in metabolic rate were approximately 18%

from the initial trial. These studies were also analyzed for mechanical efficiency, which indicated that subjects were able to make mechanical improvements during the study. The variations in stride patterns tended toward a minimum as efficiency stabilized. These mechanical improvements are marked by an increasing range of motion at joints which tends to increase stride lengths. Sparrow and Newell (1994) suggest that these results demonstrate that the increase in stride length is used as means of reducing metabolic energy expenditure.

Several other investigators have also measured habituation solely in terms of biomechanical parameters. Wall and Charteris (1980, 1981) studied mechanical habituation as the minimization in stride to stride variations in treadmill walking. Eighteen male subjects were tested on treadmill walking in 10 minute sessions twice a week for 9 weeks. The subjects had no prior experience with treadmill walking. The results indicated that there are significant variations in gait up to 45 minutes of treadmill walking, and during any session the initial two minutes are marked by a period of accommodation in which gait stabilizes. Shieb (1987) performed a similar study on novice treadmill runners and found comparable results. Six male distance runners exercised at a constant running pace on a treadmill for 15 minutes per day for 10 days. Various stride parameters were measured which indicated that most of the significant changes were seen from day 1 to day 2, with some additional changes occurring through day 3. In a study on simulated cross country skiing, Candler et al. (1995) tested 10 male subjects over three 15 minute sessions with measures of step and stride lengths. From this study, Candler et al.

concluded that at least two 15 minute practice trials were necessary for habituation to this form of exercise for these stride parameters.

Permanence of Habituation

Shephard (1969) was able to show that habituation to step-testing could be lost over the course of four weeks, while other training was being performed. Additionally, when a second habituation period was administered, the rate of habituation was greater than the first period. In the study by Sparrow and Newell (1994) on metabolic responses to treadmill crawling, it was mentioned that for the one subject in their study who had previously habituated to treadmill crawling, improving trends were seen in his performance data. These cases imply that habituation is not permanent for all forms of exercise testing, and that the rates of habituation may differ depending upon previous experience with the exercise.

In summary, past studies have shown distinct changes in exercise performance that have been attributed to the habituation associated with exercise equipment. Heart rate, oxygen consumption, and ventilation have been used as physiological markers of habituation and biomechanical variations observed during habituation have been associated with the physiological markers. In addition to physiological and biomechanical markers, Shephard also noted perceptual changes during the habituation period. The effects of habituation have been most significant at moderate intensity workloads and tend to occur in the first few trials.

EXERCISE ECONOMY

Economy refers to the "submaximal oxygen uptake per unit body weight ($\dot{V}O_{2submax}$) required to perform a given task" (Cavanagh and Kram, 1985a). Economy is also used as a measure of efficient performance. As economy reaches a stable value it can be said that habituation to the mode of exercise has been achieved for the purpose of measuring various physiological components of exercise. Specifically, if $\dot{V}O_2$ becomes stable across trials after a set number of practice trials, then for studies involving $\dot{V}O_2$ this number of practice trials is required before experimental trials should begin.

Economy is made up of several components that each affect the overall measure for an individual (Daniels, 1985; Williams et al, 1991). The purpose of this study is not to try to identify individual components, but to control outside factors that influence economy and measure the overall change in economy due to habituation. Some of the components that are influenced by outside factors are the physiological and biochemical components which are influenced by the laboratory environment and the state of rest or food intake.

Psychological State Effects

The laboratory testing environment and equipment, such as the mouthpiece, nose clip, and electrodes may produce anxiety in a subject, which in turn tends to raise heart rate and respiratory rate; therefore, overall oxygen consumption will be elevated. Erickson et al. (1946) noted statistically significant increases in efficiency from the first to the second measurement trials during treadmill test, which were independent of the amount of treadmill training subjects performed between the measurement trials. Erickson et al. (1946) attributed this increase in efficiency to 'technical training,' which they described as the psychological adaptation to the mask and other 'novel features' of the experiment. The 'novel features' associated with laboratory testing influence the psychological component of exercise economy.

Confounding Factors Affecting Physiological Measurements

Variations in the time of day can affect the heart rate response to exercise, so tests should be performed at the same time of day to eliminate this source of variation (Jones, 1988). In addition, food consumption can also affect physiological measurements. Digestion requires oxygen consumption, so while digestion takes place, the subject's basal metabolic rate will increase, thus oxygen consumption will be elevated. Other factors, such as consumption of caffeine or nicotine, will also increase metabolic rate (Jones, 1988).

Factors Associated with the Economy of Exercise

Movement of the body and its limbs is achieved by muscular contractions. These muscular contractions require the consumption of oxygen as part of the energy production process which supplies the fuel for these contractions. Muscular contractions which do not contribute to the production of measured work on an ergometer are extraneous.

These extraneous contractions contribute to oxygen consumption beyond what is necessary to maintain a fixed rate submaximal workload and can basically be viewed as inefficient (Cavanagh and Kram, 1985b). Sparrow and Irizarry-Lopez (1987) showed a significant correlation between the increase in mechanical efficiency and a decrease in caloric cost for subjects crawling on a treadmill. In addition to muscular contractions which can be measured as inefficient mechanical work, Williams (1985) has noted that isometric contractions will not show up as mechanical work but do expend metabolic energy.

The economy of muscular force production has been linked to rates of contraction (Corlett and Mahadeva, 1970; Sparrow and Irizarry-Lopez, 1987) as well as stride lengths and seat heights (Cavanagh and Kram, 1985b). These variables can be adjusted to optimal levels for each subject.

OXYGEN CONSUMPTION AND ITS RELATION TO OVERALL WORK

Oxygen consumption has been used for over 70 years as a physiological measure of work. As muscles become active to meet a mechanical demand, cellular respiration increases to supply energy to active muscles, which in turn requires cardiovascular and ventilatory responses to supply oxygen in sufficient quantities to support the regeneration of adenosine triphosphate (ATP) from adenosine diphosphate (ADP) (Wasserman, 1994). Based upon the body's inherent desire to maintain homeostasis, the supply of oxygen to the active muscles is closely matched to the amount of oxygen required for cellular respiration after a steady state of submaximal work has been reached (Wasserman, 1994). Before steady state has been reached, oxygen consumption lags work output, as explained by the oxygen deficit theory in which the initial energy demands of the active muscles are partially met through the utilization of stored energy in the form of creatine phosphate (CP) and ATP.

When $\dot{V}O_2$ (ml·kg^{-1}·min^{-1}) is plotted versus time, the resulting area under the curve is equivalent to oxygen consumption, VO_2 (ml·kg^{-1}). The summation of $\dot{V}O_2$ across time yields the oxygen consumed during that period.

"In most studies, $\dot{V}O_2$ is found to increase to steady state by 3 min if exercise is performed without a lactic acidosis, but longer with lactic acidosis" (Wasserman, 1994). For a mode of exercise at a submaximal workload, with which a subject is familiar, the typical $\dot{V}O_2$ and $\dot{V}_E$ time graphs follow a nonlinear increase from a basal metabolic rate at onset of exercise to a new steady state value (Wasserman, 1994; Whipp, 1987). Steady state values are generally reached in less than 3 minutes (Wasserman, 1994; Whipp, 1987).

Oxygen consumption is a measure of work (Whipp, 1987), therefore, lower values of oxygen consumption indicate lower energy expenditure. With the 2650UE set at a constant workload, the lower value of oxygen consumed over a fixed time interval indicates a lower energy expenditure for a given amount of work. Efficiency can be expressed as work divided by energy expended (Whipp, 1987):

Efficiency % = [(work done)/(energy cost)] * 100%

Efficiency increases as energy expended decreases for a constant workload.

For various efficiency tests, a period of habituation may be required to establish true values that are not confounded by the novelty of the equipment. In the past, studies have shown the need for periods of habituation to treadmill (Erickson, 1946) and cycle ergometry (Shephard, 1966, 1969), and more recently, studies have been performed on treadmill crawling (Sparrow and Irizarry-Lopez, 1987; Sparrow and Newell, 1994) which have used oxygen consumption as a measure of learning and efficiency for this task. Sparrow et al. (1987, 1994) concluded that with practice of a novel motor task, a reduction in oxygen consumption was achieved. From their data, Sparrow and Irizarry-Lopez (1987) noted that according to a major principle of motor skill learning, a reduction in the caloric cost of exercise accompanies changes in movement patterns which are associated with skilled performance.

The measurement of $\dot{V}O_2$ is a questionable marker of work if it significantly decreases across trials as a function of practice. At submaximal workloads, subjects will exhibit elevated $\dot{V}O_2$ values when they are training on unfamiliar equipment. Furthermore, it is predicted that a lower workload will be achieved during a true $\dot{V}O_2$ max test due to the fact that higher $\dot{V}O_2$ values will be expected at lower workloads. Therefore, when $\dot{V}O_2$ max (a physiological limit) is reached, it will be at a lower workload than could be attained if the subject had sufficient practice on the equipment (Shaw, 1996).

The decreases in $\dot{V}O_2$ with respect to a constant workload and the increases in workload with respect to a constant $\dot{V}O_2$ max that occur as a function of practice on the equipment are analogous to the strength gains seen at the beginning of a resistance training program due to neuromuscular adaptations. Just as these strength gains give the false impression of actual muscular strength increases, the initial $\dot{V}O_2$ related improvements can relay erroneous information.

ARM ERGOMETRY

Studies have shown that at a given submaximal workload, arm ergometry results in a higher $\dot{V}O_2$ requirement than leg ergometry (Franklin, 1985; ACSM, 1991). The differences between arm and leg exercise are attributed to increased peripheral vascular resistance and lower mechanical efficiencies involved with smaller muscle groups. Arm ergometry is a reproducible form of exercise testing as shown by (Franklin, 1985).

It is hard to control the level of torso muscle recruitment during standard arm ergometry (Franklin, 1985), in which subjects are limited to one plane of motion. With the 2650UE, subjects are not limited to one plane of movement, so control of muscle recruitment becomes even more variable than with the traditional arm (cycle) ergometer.

CHAPTER III

JOURNAL MANUSCRIPT

CARDIOPULMONARY ANALYSIS OF HABITUATION

TO SIMULATED KAYAK ERGOMETRY

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CARDIOPULMONARY ANALYSIS OF HABITUATION

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(ABSTRACT)

All forms of exercise equipment require a period of habituation in which individuals adapt to the novel movement required in operating the device and reach a point of physiological stability. During this adaptation period, physiological variables which indicate cardiopulmonary demand typically will change. In general, such changes are expected with devices that require complex movements. The influence of this habituation on physical performance is vital for establishing research methodology in which precise control of power output is necessary.

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Significant differences ($p<0.001$) were found for VO_2, $\dot{V}O_2$, $\dot{V}_E$, HR, and RPE across the four trials, with decreases of 6.3% to 9.5% from the mean values in trial 1 to trial 2. *Post hoc* analysis indicates that a minimum of two 10 min practice trials are required for

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key words: cardiopulmonary, oxygen consumption, habituation, kayak, ergometer

INTRODUCTION

The CrossRobics™ 2650UE (2650UE) recently has been introduced by the StairMaster® corporation for the exercise industry. This equipment differs from conventional exercise equipment in that it is designed to provide the user with arm and torso training that combines both a strength and endurance stimulus within the same exercise bout. Unlike traditional ergometers, such as the treadmill and cycle, the 2650UE simulates a kayaking movement, which involves the muscles of the arms and torso. A substantial amount of research has gone into ergometry involving the arms and legs, but very few studies have involved extensive use of the torso. One other ergometer that is based upon a kayaking motion has been developed for use in training kayakers during the off season, but there have been no published studies on the exercise adaptation time required to reach a proficient training level.

In the past, researchers have measured habituation to exercise equipment in various ways. Some studies have quantified the movement, position and angles of joints and limbs to establish the point at which these variables stabilize over time (5,23,26,27,28, 31,32), other studies have looked at variations in heart rate and oxygen consumption (13, 26,27,28).

Before subjects become habituated they will be exerting more effort than is required to maintain the workload setting on the ergometer. This extra effort results from superfluous movements of the body and limbs, as well as the development of muscular tensions which are not contributing to work output as measured by the ergometer.

Inefficient muscular contractions place a demand on the cardiorespiratory system which result in increased heart rates and levels of oxygen consumption. As subjects become habituated, response variability should be appreciably reduced. Hypothetically, both minute-by-minute variability in response and physiological demand will become stable across trials.

In order to efficiently utilize laboratory resources, while maintaining the integrity of data collection, it is essential to know the length of the habituation period for the exercise equipment on which tests will be run. For example, data collected during the habituation period will erroneously represent subject performance at the task. With this type of error entered into a series of data points, the changes associated with habituation could be mistakenly attributed to treatments across trials. Without evidence of the habituation period associated with a particular testing mode, the experimenter is confronted with uncertainty regarding the effects of any experimental intervention that may be studied via the testing mode. In terms of efficient use of laboratory resources, the time provided for habituation to equipment can quickly multiply, especially for experiments involving large numbers of subjects.

All forms of exercise equipment require a period of habituation or neuromuscular learning in which individuals adapt to the novel movement required in operating the device. During this adaptation period, physiological variables that indicate cardiopulmonary and metabolic demand typically will change. In general, such changes are most marked with devices that require complex movements. As these physiological variables fluctuate, the load settings on the equipment will not accurately or consistently reflect the biological demand levels desired by the individual. In a fitness center setting, if the responses of a first time user to an ergometer are significantly different than are expected on subsequent trials, then these responses should be related to clients. The influence of learning on physical performance also is vital for establishing research methodology in which precise control of power output is necessary. In many instances, the ability to precisely control power levels is essential in experiments where the goal is to study incremental loading effects on cardiopulmonary and metabolic functions. In our study, the variations in oxygen consumption (VO_2, $\dot{V}O_2$), ventilation ($\dot{V}_E$), heart rate (HR) and rating of perceived exertion (RPE) were used as the markers of habituation. These markers were chosen because they are variables that are commonly used to evaluate performance, so it is essential to know when they become stable over trials.

The purpose of this study was to measure and compare oxygen uptake, cardiorespiratory, and perceptual responses during a series of constant load exercise tests on the StairMaster CrossRobics™ 2650UE ergometer in healthy college-aged males and females, for assessment of the habituation period associated with these responses.

METHODS

This investigation required data collection over four submaximal exercise sessions and one maximal exercise test per subject. The submaximal sessions were performed at a fixed workload, based upon subject weight and sex, and this workload was kept constant for all four trials. During each trial, breath-by-breath gas analysis data was collected during 2 min of rest and 10 min of exercise. Heart rate was continuously monitored during the initial rest period, for 10 min of exercise, and for a recovery period while the subject rested until their heart rate returned to a rate of less than 100 beats per minute.

Subjects. Twenty-six male (N=12) and female (N=14) subjects, 18 to 32 years of age, from the Blacksburg, Virginia area participated in this study. This study was approved by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University, and informed written consent was obtained from each subject. Subjects were screened with standard procedures for a health history which would put them at risk for peak exercise testing (1). Subject data were kept confidential through the use of subject numbers.

Testing Procedures. Subjects were brought into the laboratory for an initial exposure to the respiratory gas analysis system, heart rate monitoring equipment, RPE scale (Borg scale 6-20) (1), and procedures. Subjects were seated on a cycle ergometer and instructed on the use of the RPE scale, fitted with electrodes for an ECG monitor, a nose clip and a mouthpiece for gas analysis, and then exercised submaximally as determined by RPE under these conditions for 10 min. This initial exposure period was used to reduce the elevated $\dot{V}O_2$ measurements associated with the novelty and apprehension expected from a first exposure to laboratory equipment and the testing environment, as noted by Erickson and colleagues (13). Subjects performed this exercise session on a cycle ergometer so that they could be exposed to the environment without being exposed to exercise on the 2650UE.

For all four of the submaximal exercise trials performed on the 2650UE, male subjects exercised at a setting of 5 resistance plates, while female subjects exercised at a setting of 3 plates. These settings were based upon the written recommendations for first-time users that accompanied the 2650UE. The 2650UE has a conversion based upon subject weight from watts to METs, so for each subject a speed was selected which corresponded to a setting of ~3 METs (~0.36 watts/kg) for female subjects and ~5 METs (~0.55 watts/kg) for male subjects. These settings were based upon a pilot study, performed before this experiment, which indicated that they represent submaximal work loads.

Within a week after the four submaximal trials on the 2650UE were completed, each subject was tested to peak capacity with an incremental test to determine their peak work capacity. The incremental test consisted of one minute stages with constant resistance plate settings which were dependent upon subject weight and sex. Three resistance plates were used for females <49 kg, four plates for the range 49-60 kg, and five plates for those over 60 kg. Six resistance plates were used for males <80 kg, seven plates for the range 80-95 kg, eight plates for the range 96-110 kg, and nine plates for those over 110 kg. These protocols were based upon a pilot study and were designed to bring subjects to their peak capacity in 8 to 12 minutes, which corresponded to ergometer settings of ~9

METs (~0.99 watts/kg) for females and ~12 METs (~01.32 watts/kg) for males. Oxygen consumption was monitored continuously throughout the test. Peak intensity was defined as the point at which oxygen uptake reached a plateau, the subject could not maintain the work intensity, or the subject requested to stop the test.

Measurements. Open-circuit spirometry was used to collect metabolic data during selected exercise trials. Ventilation, oxygen, and carbon dioxide content were measured using a MedGraphics® CPX/D (Minneapolis, Minnesota) metabolic cart. Subjects wore a nose clip and breathed through a standard disposable mouthpiece, which allowed them to inspire room air. Expired air was sampled as subjects breathed out through the mouthpiece, from which metabolic data was calculated and averaged over 15 sec intervals. Heart rate was measured during the last 10 sec of each minute using a simple bipolar ECG lead and recording system.

Two measures of oxygen consumption were used to evaluate habituation. For a fairly sensitive measure of oxygen consumption during the onset of exercise, VO_2 ($ml \cdot kg^{-1}$), was calculated from 15 sec averages as the total oxygen consumed over the first 6 min of exercise. To characterize the later phase of a trial, the common measure of the rate of oxygen consumption, $\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$), was calculated as the mean rate over minutes 7 through 10. The $\dot{V}_E$, HR, and RER were also calculated as mean values over minutes 7 through 10. An RPE value was taken at minute nine.

Statistics. Subject summary data was analyzed with descriptive statistics. The dependant measures of VO_2, $\dot{V}O_2$, $\dot{V}_E$, HR, RER, and RPE were analyzed with a simple ANOVA for repeated measures across trials to determine whether or not physiological parameters changed significantly across trials. When significant F-ratios were found ($p<0.001$), the Tukey *post hoc* analysis was used to locate the source of the significant variation found by ANOVA. There was no significant interaction between the responses for male and female subjects, so response data were pooled for these groups.

RESULTS

Subject mean characteristics are presented in Table 1. Mean submaximal power loads, which were used during the four constant-load exercise trials, are less than 50% of the mean peak power loads. Mean peak heart rates are approximately 90% of age predicted heart rates. The mean peak $\dot{V}O_2$ values for the male and female subjects are, respectively, ~67% and ~84% of the age predicted maximum $\dot{V}O_2$ for lower body ergometry, based upon the ACSM prediction equations for active subjects (1). Peak values for upper body ergometry are typically in the range of 60% to 90% of the maximum values which can be obtained through lower body ergometry (1,12,14).

Responses across the four constant-load exercise trials are presented in Table 2 and Figure 1. With the exception of the respiratory exchange ratio (RER), significant between trial differences were found for all parameters, with F-values ranging from 8.9 to 53.3, as shown in Table 2. The results presented in Table 2 show that the markers of cardiopulmonary demand evaluated in exercise, as well as the perceived exertion, declined after trial 1 by 6.3% to 9.5%, and tended to stabilize thereafter. Significant differences ($p<0.05$) between trials are indicated by symbols in Table 2.

DISCUSSION

Investigators have shown habituation periods associated with treadmill exercise (13,23,26,27,28,31,32) and simulated cross-country skiing (5), and the reference to familiarization periods for novel exercise has also been made (30). Following these investigations, the present study has shown that there is a habituation period associated with the StairMaster® CrossRobics™ 2650UE. Over the course of four exercise trials, it was shown that a minimum of two 10 min practice trials are required before differences in oxygen uptake responses become statistically insignificant on subsequent trials. The parameters of HR, $\dot{V}_E$, and RPE were shown to require a minimum of one 10 min trial before differences in subsequent trials became statistically insignificant.

Wall and Charteris (31,32) found that with novice treadmill exercisers there is an initial period of accommodation, which is characterized by awkward movements, and then a period of habituation in which stride to stride variations are minimized. In our study with the 2650UE, stroke to stroke motor patterns were not specifically studied, but it was noted that during the first few minutes of an initial exercise trial subject stroke patterns seemed choppy and awkward, which is analogous to the treadmill accommodation period noted by Wall and Charteris (31,32). In our study this initial accommodation period is represented by the measure of oxygen consumed over the first six minutes of exercise. Subsequent habituation was measured by the mean physiological variables for minutes seven through ten of each exercise trial.

Our data also were examined for within-subject variability as a percentage of mean responses. Becque et al. (2), found average within subject variability of steady-state $\dot{V}O_2$ to be 4.1% of the mean response when subjects exercised on a bicycle ergometer at a constant-load which represented 55% of their max; additionally, heart rate was shown to have an intrinsic day-to-day variability of 3.3%. Our data show that once response variability on the 2650UE fell to within these ranges the trial to trial differences became insignificant.

Investigations using treadmill exercise (23,31,32) have suggested that even after a subject has habituated to the task, a brief orientation period still should be employed at the beginning of an experimental trial to allow reaccommodation to the task. In view of such a finding, it might be of interest to investigators to determine the extent to which habituation to the 2650UE is relatively permanent. To this end, it would be worthwhile to study subjects at some extended period after initial habituation to evaluate whether learning effects were lost.

Researchers are often interested in maximizing performance efficiency at various tasks. The variety of motor patterns available in operation of the 2650UE suggests that there may be optimal patterns which may not be naturally selected by subjects. Brisswalter and Legros (4) have shown the ability to increase subject efficiency in treadmill running through training at optimal stride frequencies, and extensive study of the kayak stoke by Plagenhoef (21) has identified biomechanical variables which are attributes of champion flatwater kayakists. These studies imply that subject efficiency could also be improved on the 2650UE through a training program involving feedback on stroke frequencies and possibly other technique variables.

Another area of interest is the prediction of peak performance on the 2650UE. The identification of variables, such as submaximal responses and anthropometric measurements, for the prediction of peak performance would be of use in the design of protocols for peak testing. The difference in percentage of predicted $\dot{V}O_{2max}$ between male and female subjects appears to be significant and could be an interesting point for further research. The difference could be a function of the prediction equations, the sample of subjects in this experiment or possibly the peak testing protocol for the 2650UE. However, the difference could be based upon actual differences between male and female responses to this type of exercise.

The variables VO_2, $\dot{V}O_2$, $\dot{V}_E$, HR, and RPE were shown to decrease across the initial trials on the 2650UE, with a minimum of two 10 min trials for VO_2 and $\dot{V}O_2$ to become stable, and a minimum of one 10 min trial for $\dot{V}_E$, HR, and RPE to become stable. Understanding the habituation responses to the 2650UE will allow researchers to properly design studies and aid fitness professionals in the prescription of exercise.

Table 1. Subject Characteristics (mean ± SD)

	Female (N=14)*	Male (N=12)**
Age (yr)	21.5 ± 1.8	23.3 ± 3.5
Height (cm)	165.8 ± 4.1	179.3 ± 6.4
Weight (kg)	58.2 ± 6.8	85.0 ± 13.8
Submax Power (W)	21.1 ± 2.3	46.8 ± 7.9
Peak Power (W)	62.1 ± 12.7	111.0 ± 17.1
Peak $\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	30.3 ± 3.8	37.1 ± 5.4
Peak HR ($bt \cdot min^{-1}$)	183.4 ± 5.0	176.9 ± 11.1
Time to Peak (min)	9.0 ± 1.4	9.8 ± 1.0

* Two female subjects did not satisfy the requirements for a peak test, so the peak results for only 12 female subjects are included in this table.

** Only 11 male subjects were tested with the peak protocol.

Table 2. Responses across exercise trials. (mean ± SE)

	Trial 1	Trial 2	Trial 3	Trial 4	F-value
VO_2 ($ml \cdot kg^{-1}$)[a,b]	110.3 ± 3.8	99.9 ± 3.5	96.3 ± 3.2	94.7 ± 3.2	53.3
$\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$)[a,c]	19.8 ± 0.7	18.5 ± 0.7	18.0 ± 0.7	17.8 ± 0.7	26.5
HR ($bt \cdot min^{-1}$)[a]	139.4 ± 3.8	129.9 ± 3.2	129.6 ± 2.9	126.5 ± 3.1	14.0
$\dot{V}_E$ ($l \cdot min^{-1}$)[a]	41.6 ± 2.9	37.9 ± 2.6	37.1 ± 2.5	36.1 ± 2.3	18.8
RPE[a]	13.1 ± 0.4	12.2 ± 0.4	11.8 ± 0.5	11.9 ± 0.5	8.9
RER	0.97±0.01	0.97±0.01	0.97±0.01	0.97±0.01	0.1

[a] Significant differences between trial 1 and subsequent trials.

[b] Significant differences between trial 2 and subsequent trials.

[c] Significant difference between trial 2 and trial 4.

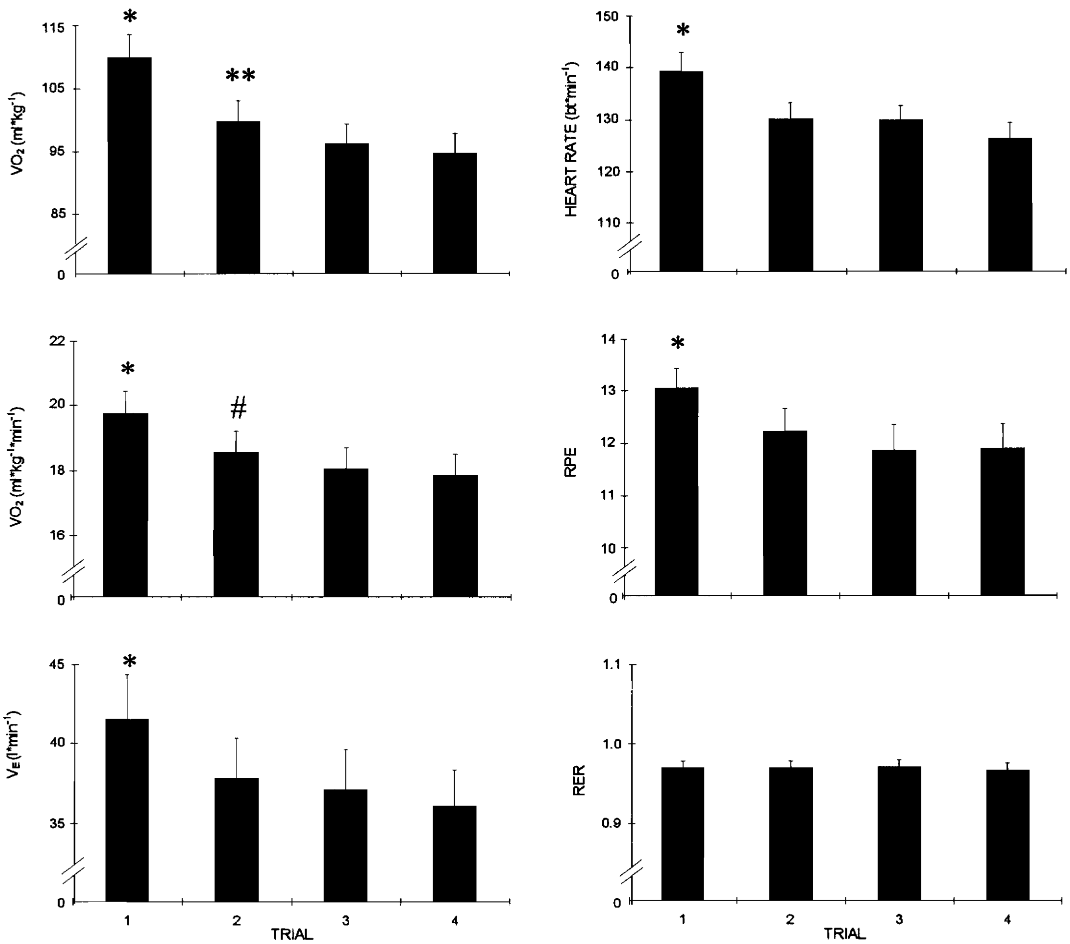

Figure 1. Responses across the first four 10 min trials of constant-load submaximal exercise (mean + SE). * significantly different from trials 2,3, and 4; ** significantly different from trials 1,3, and 4; # significantly different from trials 1 and 4.

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CHAPTER IV

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

SUMMARY

All forms of exercise equipment require a period of habituation or neuromuscular learning in which individuals adapt to the novel movement required in operating the device. During this adaptation period, physiological variables that indicate cardiopulmonary and metabolic demand typically will change. In general, such changes are most marked with devices that require complex movements. As these physiological variables fluctuate, the load settings on the equipment will not accurately or consistently reflect the biological demand levels desired by the individual. In a fitness center setting, if the responses of a first time user to an ergometer are significantly different than are expected on subsequent trials, then these responses should be related to clients. The influence of learning on physical performance is also vital for establishing research methodology in which precise control of power output is necessary. In many instances, the ability to precisely control power levels is essential in experiments where the goal is to study incremental loading effects on cardiopulmonary and metabolic functions. In this study, the variations in oxygen consumption (VO_2, $\dot{V}O_2$), ventilation ($\dot{V}_E$), heart rate (HR) and rating of perceived exertion (RPE) were used as the markers of habituation. These markers were chosen because they are variables that are commonly used to evaluate performance, so it is essential to know when they become stable over trials. The purpose of this study was to measure and compare oxygen uptake, cardiorespiratory, and perceptual responses during a series of constant load exercise tests on the StairMaster® CrossRobics™ 2650UE ergometer in healthy college-aged males and females, for assessment of the habituation period associated with these responses.

Twenty-six male (N=12) and female (N=14) subjects participated in this study. Mean submaximal power loads, which were used during the four constant-load exercise trials, are less than 50% of the mean peak power loads. Mean peak heart rates are approximately 90% of age predicted heart rates. The mean peak $\dot{V}O_2$ values for the male and female subjects are, respectively, ~67% and ~84% of the age predicted maximum $\dot{V}O_2$ for lower body ergometry based upon the ACSM prediction equations for active subjects (ACSM, 1991). Peak values for upper body ergometry are typically in the range of 60% to 90% of the maximum values which can be obtained through lower body ergometry (ACSM, 1991; Enders et al., 1994; Franklin, 1985).

With the exception of the respiratory exchange ratio (RER), significant differences between trials were found for all parameters, with F-values ranging from 8.9 to 53.3. The results show that the markers of cardiopulmonary demand evaluated in exercise as well as the perceived exertion declined after trial 1 by 6.3% to 9.5% and tended to stabilize thereafter.

CONCLUSIONS

Investigators have shown habituation periods associated with treadmill exercise (Erickson et al., 1946; Schieb, 1986, Sparrow et al. 1987, 1994), bicycle ergometry (Shephard, 1966, 1969; Davies et al., 1968), and simulated cross-country skiing (Candler et al., 1995), and the reference to familiarization periods for other novel exercise has also been made (Stenberg et al, 1967). Following these investigations, the present study has shown that there is a habituation period associated with the StairMaster® CrossRobics™ 2650UE. Over the course of four exercise trials, it was shown that a minimum of two 10 min practice trials are required before differences in oxygen uptake responses become statistically insignificant on subsequent trials. The parameters of HR, $\dot{V}_E$, and RPE were shown to require a minimum of one 10 min trial before differences in subsequent trials became statistically insignificant.

Wall and Charteris (1980, 1981) found that with novice treadmill exercisers there is an initial period of accommodation, which is characterized by awkward movements, and then a period of habituation in which stride to stride variations are minimized. In the study with the 2650UE, stroke to stroke motor patterns were not specifically studied, but it was noted that during the first few minutes of an initial exercise trial subject stroke patterns seemed choppy and awkward, which is analogous to the treadmill accommodation period noted by Wall and Charteris (1980, 1981). In our study this initial accommodation period is represented by the measure of oxygen consumed over the first six minutes of exercise. Subsequent habituation was measured by the mean physiological variables for minutes seven through ten of each exercise trial.

Our data also were examined for within subject variability as a percentage of mean responses. Becque et al. (1993), found average within subject variability of steady-state $\dot{V}O_2$ to be 4.1% of the mean response when subjects exercised on a bicycle ergometer at a constant load which represented 55% of their max; additionally, heart rate was shown to have an intrinsic day-to-day variability of 3.3%. Our data show that once response variability on the 2650UE fell to within these ranges the trial to trial differences became insignificant. The variables VO_2, $\dot{V}O_2$, $\dot{V}_E$, HR, and RPE were shown to decrease across the initial trials on the 2650UE, with a minimum of two 10 min trials for VO_2 and $\dot{V}O_2$ to become stable, and a minimum of one 10 min trial for $\dot{V}_E$, HR, and RPE to become stable. Understanding the habituation responses to the 2650UE will allow researchers to properly design studies and aid fitness professionals in the prescription of exercise.

RECOMMENDATIONS FOR FUTURE RESEARCH

Investigations using treadmill exercise (Schieb, 1987; Wall and Charteris, 1980, 1981) have suggested that even after a subject has habituated to the task, a brief orientation period still should be employed at the beginning of an experimental trial to allow reaccommodation to the task. In view of such a finding, it might be of interest to investigators to determine the extent to which habituation to the 2650UE is relatively permanent. To this end, it would be worthwhile to study subjects at some extended period after initial habituation to evaluate whether learning effects were lost.

Researchers are often interested in maximizing performance efficiency at various tasks, and the variety of motor patterns available in operation of the 2650UE suggests that there may be optimal patterns which may not be naturally selected by subjects. Brisswalter and Legros (1995) have shown the ability to increase subject efficiency in treadmill running through training at optimal stride frequencies, and extensive study of the kayak stoke by Plagenhoef (1979) has identified biomechanical variables which are attributes of champion flatwater kayakists. These studies imply that subject efficiency could also be improved on the 2650UE through a training program involving feedback on stroke frequencies and possibly other technique variables. The 2650UE allows the user to vary stroke speed and frequency to maintain a constant workload, so a study in which subjects exercised at various stroke rates for a constant submaximal workload could evaluate physiological efficiencies over a range of stroke rates.

Another area of interest is the prediction of peak performance on the 2650UE. The identification of variables, such as submaximal responses and anthropometric measurements, for the prediction of peak performance would be of useful in the design of protocols for peak testing. Some variables that seem to be of value are heart rate at submaximal constant load values, height, weight, percent body fat, and dimensions of the upper arm.

The difference in percentage of predicted $\dot{V}O_{2max}$ between male and female subjects could be an interesting point for further research. The difference could be a function of the prediction equations, the sample of subjects in this experiment or possibly the peak testing protocol for the 2650UE. However, the difference could be based upon actual differences between male and female responses to this type of exercise. To evaluate this difference, actual lower body (treadmill or cycle ergometry) peak testing should be compared with peak testing on the 2650UE to rule out the possibility of invalid prediction of peak lower body $\dot{V}O_2$. Additionally, more than one protocol design could be used to verify peak performance on the 2650UE. The differences between male and female performance could possibly be due to differences in muscle recruitment.

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APPENDIX A

METHODOLOGY

METHODOLOGY

This investigation required data collection over four submaximal exercise sessions and one maximal exercise test per subject. The submaximal sessions were performed at a fixed workload, based upon subject weight and sex, and this workload was kept constant for all four trials. During each trial, breath-by-breath gas analysis data was collected during two minutes of rest and ten minutes of exercise. Heart rate was continuously monitored during the initial rest period, for ten minutes of exercise, and for a recovery period while the subject rested until their heart rate returned to a rate of less than 100 beats per minute.

Subjects. Fifty-one subjects, 18 to 32 years of age were recruited from the Blacksburg, Virginia area for participation in this study. Primarily, subjects were recruited by verbal requests for volunteers from a local martial arts school and classes in War Memorial Hall. Twenty-one subjects were used in a pilot study as detailed in Appendix B and 26 male (N=12) and female (N=14) subjects participated in the main study as outlined in this section. Four female subjects were dropped from the study, one was dropped after the development of contraindicated cardiac rhythms during submaximal exercise, another became ill after recruitment, and the final two could not comply with the testing schedule. This study was approved by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University, and informed written consent (Appendix C) was obtained from each subject. Subjects were screened with a physical activity readiness questionnaire (Appendix D). If a subject answered yes to any of the first seven questions on the PAR-Q, he or she was excluded from the study. Additionally, subjects that answer yes to two or more major coronary risk factor questions were excluded from the study. Subject data was kept confidential through the use of subject numbers.

Testing Procedures. Subjects were brought into the laboratory for an initial exposure to the respiratory gas analysis system, heart rate monitoring equipment, RPE scale (Borg 6-20) (ACSM, 1991), and procedures. Subjects were seated on a cycle ergometer and instructed on the use of the RPE scale, fitted with electrodes for an ECG monitor, a nose clip and a mouthpiece for gas analysis, and then exercised submaximally, as determined by RPE, under these conditions for ten minutes. This initial exposure period was used to reduce the elevated $\dot{V}O_2$ measurements associated with the novelty and apprehension associated with a first exposure to laboratory equipment and the testing environment, as noted by Erickson and colleagues (1946). Subjects performed this exercise session on a cycle ergometer so that they could be exposed to the environment without being exposed to exercise on the 2650UE.

Instructions: Since the 2650UE requires that subjects maintain a two handed grip on the bar during exercise and the gas analysis procedure requires that subjects do not talk, RPE values could not be determined by the common means of either the subject pointing to a value or speaking. For the determination of RPE values, the following instructions were read to subjects:

- Maintain the pace at which you are working.

- Read the descriptions of the levels of exertion on the RPE scale.
- Rate your overall feeling of exertion. Don't concentrate on a particular segment of your body.
- A test technician will trace a finger down the RPE scale.
- When the technician reaches the number corresponding to your overall exertion extend your right index finger to indicate this point.

For operation of the 2650UE, all subjects were given introductory instructions in the following manner. A sheet with the following instructions was read by one of the test administrators.

- Sit on the kayak ergometer and position feet comfortably on the foot rests.
- Grasp the handlebar comfortably with your hands evenly spaced.
- Pull down and back with one hand, while pushing up and forward with the other, bringing your forward hand across the centerline of your body.
- Maintain a relatively erect posture during the test.
- Keep the plates at about eye level, between the pieces of tape.

The administrator then demonstrated the proper motion for 15 seconds. These instructions are only given before the first test and no feedback on how to operate the 2650UE was given to subjects after this point. The purpose of this limited feedback was to standardize the information that subjects would receive to eliminate the possibility of teaching or coaching the subject.

For all four of the submaximal exercise sessions performed on the 2650UE, male subjects exercised at a setting of 5 resistance plates, while female subjects exercised at a setting of 3 plates. These settings were based upon the recommendations for first-time users accompanying the 2650UE. For each subject, the 2650UE was set to a speed, dependant upon subject weight, which corresponded to ~0.36 watts/kg for female subjects and ~0.55 watts/kg for male subjects. These speeds corresponded to 2650UE display settings of ~3 and ~5 METs, respectively. These MET settings were based upon the pilot study (Appendix B) which indicated that these settings represented submaximal work rates.

Within a week after the four submaximal trials on the 2650UE were completed, each subject was tested to peak capacity with an incremental test to determine their peak work capacity. The incremental test consisted of one minute stages with constant resistance plate settings which were dependent upon subject weight and sex. Three resistance plates were used for females <49 kg, four plates for the range 49-60 kg, and five plates for those over 60 kg. One highly fit, 56 kg female was tested with five plates, based upon our experience from the pilot study. Six resistance plates were used for males <80 kg, seven plates for the range 80-95 kg, eight plates for the range 96-110 kg, and nine plates for those over 110 kg. These protocols were established through pilot testing (Appendix B) to bring subjects to their peak capacity in 8 to 12 minutes, which corresponded 2650UE settings of ~9 METs (~0.99 watts/kg) for females and ~12 METs (~1.32 watts/kg) for males. Oxygen consumption was monitored continuously throughout the test. Peak intensity was defined as the point at which oxygen uptake reached a plateau, the subject could not maintain the work intensity, or the subject requested to stop the test.

Measurements. Subjects were weighed to the nearest 0.1 kg, height was measured to the nearest 0.5 cm, upper arm circumference was measured to the nearest 0.25 cm, and tricep skinfold was measured to the nearest 0.2 mm. Open-circuit spirometry was used to collect metabolic data during selected exercise sessions. Expired ventilation, oxygen, and carbon dioxide content were measured using a MedGraphics® CPX/D (Minneapolis, Minnesota) metabolic cart that was calibrated before each test. Subjects wore a nose clip and breathed through a standard disposable mouthpiece, which allowed them to inspire room air. Expired air was sampled as subjects breathed out through the mouthpiece. Heart rate was measured using a LifePak® 9 ECG monitoring system. Three disposable ECG electrodes were placed on the subject's skin to provide a modified bipolar lead (two on the torso and one above the left ankle) and were attached to the ECG monitor. Heart rate was taken during the last ten seconds of each minute, and measured across five QRS cycles. The position of the weight stack (above, between, or below tape) was noted during the test. Notes on technique, range of motion, and hand placement were also made during the test.

Statistics. Subject summary data was analyzed with descriptive statistics. The dependant measures of VO_2, $\dot{V}O_2$, $\dot{V}_E$, HR, RER, and RPE were analyzed with a simple ANOVA for repeated measures across trials to determine whether or not physiological parameters changed significantly across trials. When significant F-ratios were found ($p<0.001$), the Tukey *post hoc* analysis was used to locate the source of the significant variation found by ANOVA. There was no significant interaction between the responses for male and female subjects, so response data was pooled for these groups.

APPENDIX B

PILOT STUDY

INTRODUCTION

Two pilot studies were conducted prior to the main study. The initial pilot study included one male and one female subject for the purpose of estimating the number of constant load submaximal trials are required for habituation. A second purpose of this pilot study was to determine what percentage of peak capacity was represented by the submaximal workloads. Additionally, this study provided practice for technicians and an opportunity to identify procedural problems.

Pilot Study 1. Two initial subjects were recruited to estimate the number of submaximal trials necessary for the study and to establish testing procedures. Each pilot subject read and signed an informed consent (Appendix C) and filled out a screening questionnaire (Appendix D), as outlined in Appendix A. The testing procedures detailed in Appendix A were followed for these two pilot subjects, with the exceptions of the workload setting for the female subject and the peak test protocol.

Based upon the recommendations written on the UE2650, male subjects exercised at a setting of 5 plates, while female subjects exercised at a setting of 3 plates. After plate settings have been selected, the UE2650 can be set to various speeds which correspond to power levels measured in watts. For convenience, entry of a subject's weight allows for conversion of watts to approximate MET levels. These approximate MET levels were used to standardize workloads for subject's weight. Initially, to keep the exercise sessions at a tolerable submaximal level, a workload of ~5 METs was selected for both male and female subjects. A workload of 5 METs corresponds to less than 60% of the predicted

$\dot{V}O_{2max}$ for females thirty-two years of age and younger and less than 55% of the predicted $\dot{V}O_{2max}$ for males thirty-two years of age and younger. In this pilot test, the female subject exercised at constant load setting ~5 METs, as opposed to the ~3 MET setting used in the full study. For both pilot subjects the peak test protocol consisted of 1.5 min stages.

Gas analysis and heart rate data were collected on one male and one female subject over the course of four submaximal exercise sessions and one incremental exercise session. The results of these trials showed significant decreases in oxygen consumption over the first six minutes of exercise from trial one to trial two, smaller decreases from trial two to trial three, and minor differences between trials 3 and 4. The male subject had a slight increase in oxygen consumption from trial 3 to trial 4, while the female subject had a slightly lower oxygen consumption in trial 4 then in trial 3. The results of these 4 trials indicated that a majority of the improvements in oxygen consumption would occur in the first 4 trials. These two pilot subjects were then tested with the incremental exercise protocol to establish their peak $\dot{V}O_2$ values. These peak values were used to determine the percentage of peak that their submaximal training corresponded to, as well as to establish a comparison between measured MET values and the corresponding MET settings on the UE2650.

The results of this initial pilot study suggested that four submaximal trials would be sufficient to detect differences across trials. The results also indicated that the workload of 5 METs was well tolerated by the male subject, eliciting mean heart rate responses of less than 60% of the maximum predicted heart rate, but this workload was not well tolerated by the female subject in which heart rate responses were greater than 80% of the maximum predicted heart rate.

Another problem encountered was that this female subject was able to maintain the workload at the highest speed setting when three resistance plates were used, so our initial peak test was not properly designed to allow the subject to reach their own peak work rate. In view of these findings, a second pilot study was undertaken to establish a suitable submaximal workload for female subjects and to determine an appropriate incremental peak test protocols for both male and female subjects.

Pilot Study 2. Twenty-one subjects, 11 male and 10 female, were tested twice at constant submaximal workloads and once with a incremental peak test on the 2650UE. Heart rate data was measured at the end of every minute with a ECG recorder and RPE values were taken at minutes 5 and 9 for both submaximal trials and at the end of each stage for the incremental test.

With the results of the first pilot study in mind, a lower workload of ~4 METs was used to test another female subject, but once again the heart rate response was greater than 80%, so a workload of ~3 METs was established for female subjects. The ~3 MET workload was tolerated well by the 10 female subjects in the second pilot study and was subsequently used as the submaximal workload for the study in which gas analysis was used to measure physiological adaptation.

Rates of Perceived Exertion (RPE) were below 14 (Borg scale of 6 to 20) (ACSM, 1991), for all 11 male and 10 female pilot subjects at the respective workloads of

~5 and ~3 METs, respectively, which indicated that these subjects felt that they were working submaximally. Additionally, heart rates at these workloads indicated that the pilot subjects were working submaximally.

Various incremental protocols were used to test the pilot subjects to peak exertion. These protocols varied in length of stage time, number of plates, and beginning workload. From these experiments, it was determined that 1 minute stages with plate settings based upon subject weight would be used during the study. Initial workloads were selected so that male subjects would reach a setting of ~12 METs at the end of ten minutes, while the initial workload for female subjects was selected so that a setting of ~9 METs would be reached at the end of ten minutes. These protocols were established to bring subjects to their peak capacity in 8 to 12 minutes.

APPENDIX C

INFORMED CONSENT

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants
of Investigative Projects

TITLE

Adaptation Time for a Kayak Ergometer

PRINCIPAL INVESTIGATOR

Christopher E. Callaghan, graduate student, Exercise Science Program, Department of Human Nutrition and Foods

PURPOSE OF THE RESEARCH

You are invited to participate in a study about the verification of workload settings on a kayak ergometer and time required to become proficient at exercising on the kayak ergometer.

PROCEDURES

The study will consist of up to 12 exercise sessions at a moderate intensity workload (<75% maximum oxygen uptake, $\dot{V}O_{2max}$), and one incremental exercise bout to determine your peak work capacity. The incremental exercise bout will begin at a low workload setting and will become progressively more difficult as the workload is increased at regular intervals until a peak intensity is reached. Peak intensity will be defined as the point at which oxygen uptake plateaus, you cannot maintain the work intensity, or you request to stop the test. During the exercise bouts, your heart rate will be monitored with a three-lead ECG, and samples of your expired air be monitored with metabolic gas analysis equipment.

POTENTIAL RISKS

The exercise performed will be moderate intensity, but as with any new exercise, there will some level of muscle soreness over the first few sessions. During the peak intensity exercise test, there is the possibility of abnormal blood pressure responses, fainting, disorders of heart rhythm, and very rare instances of heart attack. However, this is unlikely in a young healthy population.

Personnel certified in CPR and first aid will be present for all sessions, and a nurse certified in Advanced Cardiac Life Support will be present during the peak intensity exercise test. A phone will be available to contact the rescue squad for any medical emergencies.

BENEFITS OF PARTICIPATION

No guarantee of benefits has been made to encourage you to participate.

EXTENT OF ANONYMITY AND CONFIDENTIALITY

The results of this study will be kept strictly confidential. At no time will the researchers release the results of the study to anyone other than individuals working on the project without your written consent. The information you provide will have your name removed and only a subject number will identify you during analyses and any written reports of the research.

FREEDOM TO WITHDRAW

You are free to withdraw from this study at any time without penalty. You may be asked to withdraw from the study if you become ill or injured.

APPROVAL OF RESEARCH

This research project has been approved, as required by the Institutional Review Board for projects involving human subjects at Virginia Polytechnic Institute and State University.

SUBJECT'S RESPONSIBILITIES

I know of no reason that I cannot participate in this study. I have the following responsibilities:

1. To advise the researchers of any pre-existing condition that may affect my participation, such as, but not limited to, diabetes, heart conditions, muscle, bone, or joint problems, and major organ malfunctions.

2. To advise the researchers of any prescribed medications, for the treatment of an illness or disorder, which I may be taking during the course of this experiment.

3. To advise the researchers of any medical problems that might arise in the course of this experiment, such as signs of strains, sprains, tendinitis, or bursitis; or any signs or symptoms of illness.

4. To remain in laboratory for 30 minutes after maximal exercise test, so that researchers can monitor your return to pre-exercise conditions for heart rate and blood pressure.

RELEASE

In consideration of my participation in this program, I hereby release, hold harmless and indemnify Virginia Polytechnic Institute and State University, and their agents, officers and employees from any and all liability or responsibility for any injury, illness, or resultant complications which might arise out of my participation in this program.

I have read and understand the informed consent and conditions of this project. I have had all of my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project.

If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project.

____________________ ____________________ ______

Participant's Signature   Participant's Printed Name   Date

____________________ ______

Christopher E. Callaghan   Date

Should I have any questions about this research or its conduct, I will contact:

Christopher E. Callaghan, principal investigator: 951-7325

William G. Herbert, Ph.D., faculty advisor: 231-6565

Ernest Stout, Chairman of the Virginia Tech IRB: 231-9359

APPENDIX D
SCREENING QUESTIONNAIRE

Physical Activity Readiness Questionnaire (PAR-Q)

YES NO 1. Has your doctor ever said that you have heart trouble?

YES NO 2. Do you have chest pain brought on by physical activity?

YES NO 3. Have you developed chest pain within the past month?

YES NO 4. Do you tend to lose consciousness or fall over as a result of dizziness?

YES NO 5. Do you have a bone or joint problem that could be aggravated by the proposed physical activity?

YES NO 6. Has a doctor ever recommended medication for your blood pressure or a heart condition?

YES NO 7. Are you aware, through your own experience or a doctor's advice, of any other physical reason against your exercising without medical supervision?

Major Coronary Risk Factors

YES NO Has a doctor ever told you that you have high blood pressure?

YES NO Have you ever been told that you have high cholesterol ($\geq$240 mg/dL)?

YES NO Has a doctor ever told you that you have diabetes mellitus?

YES NO Have you ever smoked cigarettes?

YES NO Has anyone in your family been diagnosed with heart disease or other atherosclerotic disease before the age of 55?

Medications

YES NO Are you currently taking any medications?

List:

____

____

Taken for what reasons?

____

____The above questions have been answered truthfully and to the best of my knowledge. I am not withholding any information regarding my health status which would place me at increased risk of injury or cardiovascular problems by participating in this study?

Printed Name:____________________ Signature:__________________ Date:_____

Witness:________________________ Signature:__________________ Date:_____

APPENDIX E

DATA SHEETS

KAYAK ERGOMETER STUDY

Subject Name: ______________________________

	Dates:	Times:
Initial Visit:	__________	__________
Visit #1:	__________	__________
Visit #2:	__________	__________
Visit #3:	__________	__________
Visit #4:	__________	__________
Max Test:	__________	__________

Subject Instructions:

1) Do not have caffeine for 12 hours before a test session.
2) Do not exercise (running, aerobics, weight lifting...) for 12 hours before a test session.
3) Do not eat or drink (except water) for two hours before a test session.
4) Do not drink alcohol the night before a test session.
5) Do not use tobacco products for 12 hours before a test session.
6) Inform the testers if you acquire a cold or other illness during the study.
7) Inform the testers if you will miss a test session.

Chris Callaghan can be reached at 951-7325 (home)
231-5006 (lab)
231-4900 (GTA office)

Should I have any questions about this research or its conduct, I will contact:

Christopher E. Callaghan, principal investigator: 951-7325

William G. Herbert, Ph.D., faculty advisor: 231-6565

Ernest Stout, Chairman of the Virginia Tech IRB: 231-9359

KAYAK ERGOMETER STUDY

Subject Name: ____

Date of Birth: _________ Gender: _____ Phone Number: ___________

Height: ____________ cm ___________ in

Weight: ____________ kg ___________ lbs ---> METS ________

Upper Arm Circumference: _____ _____ _____ --> avg. _____ cm

Tricep Skinfold: _____ _____ _____ --> avg. _____ mm

Informed Consent: _____ Activity Questionnaire: _____

PAR-Q: _____

	Dates:	Times:	RPE6:	RPE9:	ROM:	Grip:	Plates:
Initial Visit:	_____	_____	_____	_____	_____	_____	_____
Visit #1:	_____	_____	_____	_____	_____	_____	_____
Visit #2:	_____	_____	_____	_____	_____	_____	_____
Visit #3:	_____	_____	_____	_____	_____	_____	_____
Visit #4:	_____	_____	_____	_____	_____	_____	_____
Max Test:	_____	_____	_____	_____	_____	_____	_____

Subject Instructions:
1) Do not have caffeine for 12 hours before a test session.
2) Do not exercise (running, aerobics, weight lifting...) for 12 hours before a test session.
3) Do not eat or drink (except water) for two hours before a test session.
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Chris Callaghan can be reached at 951-7325 (home)
231-5006 (lab) 231-4900 (GTA office)

APPENDIX F

SUBJECT DESCRIPTIVE CHARACTERISTICS

Subject Descritive Characteristics

Subject ID	Age	Height (cm)	Weight (kg)	Workload METS	Upper Arm Girth (cm)	Tricep Skinfold (mm)
Female Subjects						
1	21	163.0	65.7	3.0	27.3	16.9
2	22	170.0	49.4	3.3	22.3	12.7
3	26	171.0	59.5	3.4	25.0	12.3
4	21	165.0	48.7	3.4	21.0	9.7
5	21	164.0	57.7	3.5	24.0	8.4
6	22	167.5	60.8	3.3	26.0	9.7
7	22	164.5	63.7	3.1	28.7	26.0
8	20	168.0	64.1	3.1	31.0	27.0
9	18	169.0	51.6	3.2	22.0	11.4
10	22	161.5	49.3	3.3	22.0	8.1
11	21	158.0	58.0	3.4	29.2	19.3
12	20	166.5	56.2	3.5	24.5	17.1
13	23	172.0	58.9	3.4	23.0	10.2
14	22	161.0	71.2	3.3	28.3	27.2
Mean	21.5	165.8	58.2	3.3	25.3	15.4
SD	1.8	4.1	6.8	0.2	3.2	7.0
Male Subjects						
15	27	182.0	84.7	5.3	33.8	7.4
16	22	183.0	81.5	4.8	33.3	10.9
17	20	179.5	84.2	5.4	34.0	5.7
18	22	178.0	69.0	4.8	26.3	6.9
19	22	178.5	68.5	4.9	27.5	8.3
20	24	163.5	79.1	4.9	30.0	17.1
21	26	190.0	101.0	5.1	33.8	20.9
22	20	180.0	116.8	4.9	40.3	15.9
23	32	186.0	91.7	4.9	34.5	12.5
24	21	178.5	91.7	4.9	31.0	15.4
25	21	177.0	76.0	5.1	31.0	10.7
26	23	176.0	75.7	5.2	30.2	12.5
Mean	23.3	179.3	85.0	5.0	32.1	12.0
SD	3.5	6.4	13.8	0.2	3.7	4.6

Peak Test Summary Data

Subject ID	Number of Plates	Peak Kayak Setting (METs)	VO_2 peak (ml/kg/min)	Peak HR (bt/min)	Total Time (min)	Peak RPE	Peak RER
Female Subjects							
1	5	9.6	30.3	192	10.5	20	1.2
2	4	8.3	27.4	183	10.3	19	1.2
3	5	9.6	29.0	179	7.5	20	1.1
5	5	13.0	36.2	179	10.2	15	1.1
6	5	12.3	37.5	183	10.8	19	1.1
7	5	10.9	28.8	188	9.5	19	1.2
8	4	7.9	25.3	185	8.8	20	1.3
10	4	9.2	31.6	183	8.0	20	1.3
11	4	7.9	30.2	183	7.0	15	1.1
12	4	9.0	27.1	190	9.8	20	1.2
13	4	9.4	33.1	183	8.7	20	1.1
14	5	7.2	26.6	174	6.7	17	1.0
Mean	4.5	9.5	30.3	183.4	9.0	18.7	1.2
SD	0.5	1.8	3.8	5.0	1.4	1.9	0.1
Male Subjects							
15	7	12.4	37.7	174	8.6	19	1.1
16	7	13.9	43.8	183	10.5	19	1.2
18	6	14.1	39.9	174	10.5	20	1.2
19	6	10.0	31.1	155	8.3	20	1.2
20	6	11.3	32.8	188	10.8	20	1.2
21	8	10.9	32.8	183	9.3	20	1.2
22	9	10.6	31.8	188	9.7	20	1.2
23	7	12.3	37.2	179	10.9	20	1.2
24	7	11.4	36.8	174	9.7	18	1.1
25	6	10.9	35.8	160	8.3	17	1.2
26	6	13.7	48.8	188	11.0	20	1.1
Mean	6.8	12.0	37.1	176.8	9.8	19.4	1.2
SD	1.0	1.4	5.4	11.1	1.0	1.0	0.0
Subjects with insufficient peak tests							
4	3	6.3	20.2	150	8.2	14	1.2
9	4	6.1	17.3	144	6.0	15	1.2

APPENDIX G

DATA TABLES

Oxygen Consumption Data (ml/kg for first 6 minutes of exercise)

Subject ID	Trial 1	Trial 2	Trial 3	Trial 4
Female Subjects				
1	93.0	67.7	69.7	68.2
2	88.3	89.8	80.9	83.4
3	85.5	78.6	77.4	78.3
4	88.2	77.0	81.8	75.6
5	119.9	91.9	93.1	94.1
6	88.8	81.7	81.5	72.7
7	101.0	87.5	82.4	73.1
8	91.6	83.1	80.6	75.0
9	93.7	89.3	85.6	82.6
10	97.1	95.0	84.9	91.3
11	92.2	82.7	83.5	82.7
12	102.4	96.4	90.6	91.0
13	108.4	101.2	94.0	87.6
14	113.8	102.2	91.4	94.8
Male Subjects				
15	149.7	140.4	129.9	124.9
16	127.2	119.5	112.4	105.8
17	149.3	126.3	117.7	106.6
18	111.1	98.0	93.4	95.7
19	127.0	110.6	112.6	110.0
20	120.2	107.7	106.1	109.9
21	111.9	104.3	104.8	105.7
22	98.8	96.9	97.3	95.6
23	105.4	100.7	100.2	101.3
24	133.7	115.8	103.9	113.3
25	126.3	125.5	123.8	119.4
26	143.8	127.1	123.9	123.0
Mean	110.3	99.9	96.3	94.7
SE	3.8	3.5	3.2	3.2

Mean VO2 (ml/kg/min) min 7-10

Subject ID	Trial 1	Trial 2	Trial 3	Trial 4
Female Subjects				
1	15.8	12.8	12.6	12.6
2	15.6	15.8	15.0	15.0
3	15.8	14.3	13.9	14.2
4	16.1	15.3	15.5	14.3
5	18.8	16.1	16.4	16.1
6	14.6	14.0	14.1	12.9
7	17.7	15.6	15.1	12.9
8	15.6	15.3	14.9	14.5
9	16.6	15.8	15.5	15.4
10	17.4	16.9	15.7	16.8
11	17.0	15.9	15.4	16.0
12	19.7	17.4	17.1	16.8
13	18.8	16.8	16.7	15.9
14	19.9	18.3	17.5	18.3
Male Subjects				
15	25.9	26.2	23.8	22.4
16	23.5	22.0	20.5	19.5
17	25.8	21.6	20.4	20.2
18	18.5	17.9	16.4	17.7
19	21.6	19.4	20.8	21.3
20	24.0	21.6	20.2	21.6
21	21.4	20.0	21.0	20.1
22	19.4	20.4	19.9	19.7
23	20.5	21.1	20.2	20.1
24	25.0	21.9	20.6	22.4
25	23.1	24.6	23.5	22.5
26	25.7	24.1	25.5	24.0
Mean	19.8	18.5	18.0	17.8
SE	0.7	0.7	0.7	0.7

Mean VE (L/min) min 7-10

Subject ID	Trial 1	Trial 2	Trial 3	Trial 4
Female Subjects				
1	32.2	23.4	23.9	23.4
2	25.0	26.2	24.4	23.9
3	25.8	23.7	23.7	24.6
4	26.8	25.7	26.8	25.8
5	30.0	25.6	27.7	26.9
6	27.3	24.6	26.9	23.7
7	33.2	27.0	25.4	22.9
8	30.2	32.0	31.4	30.9
9	28.6	26.5	23.9	26.1
10	28.0	25.4	23.7	26.8
11	29.5	29.5	28.6	29.6
12	32.8	30.6	27.3	26.6
13	36.9	29.2	28.8	26.7
14	35.7	37.3	34.1	36.8
Male Subjects				
15	55.1	52.9	47.4	42.6
16	54.3	44.7	44.5	42.5
17	65.2	47.8	46.4	44.9
18	35.5	36.1	35.1	34.6
19	44.4	40.2	41.2	43.5
20	57.9	48.1	45.2	48.2
21	61.7	59.1	62.5	53.6
22	73.0	68.7	66.7	62.5
23	53.1	52.5	52.2	50.6
24	65.6	56.7	54.1	52.2
25	45.6	46.5	45.7	43.5
26	48.0	44.1	48.0	45.2
Mean	41.6	37.8	37.1	36.1
SE	2.9	2.6	2.5	2.3

Subject Mean Heart Rates (minutes 7-10) Trials 1-4

Subject ID	Trial 1	Trial 2	Trial 3	Trial 4
Female Subjects				
1	153	120	126	113
2	136	121	132	134
3	121	130	129	128
4	122	124	141	112
5	112	102	103	107
6	99	101	112	98
7	124	105	100	95
8	153	145	141	153
9	131	147	125	119
10	127	124	115	122
11	139	130	133	120
12	170	158	151	139
13	140	130	124	131
14	163	127	141	141
Male Subjects				
15	155	147	141	129
16	112	102	103	107
17	173	147	145	135
18	131	113	117	123
19	125	117	125	127
20	162	146	138	141
21	157	155	155	160
22	153	152	150	145
23	118	115	115	105
24	147	134	133	129
25	115	121	110	110
26	141	129	136	131
Mean	138	129	129	125
SE	3.8	3.2	2.9	3.1

RPE minute 9 (Borg Scale 6-20)

Subject ID	Trial 1	Trial 2	Trial 3	Trial 4
Female Subjects				
1	11	9	8	7
2	15	13	12	11
3	15	14	14	13
4	13	13	13	14
5	12	11	10	10
6	11	10	9	10
7	10	9	8	9
8	16	17	16	14
9	10	9	9	12
10	13	13	13	13
11	11	10	10	10
12	15	13	13	13
13	14	14	13	13
14	17	14	14	14
Male Subjects				
15	17	15	17	16
16	12	12	11	12
17	11	8	6	6
18	13	14	14	14
19	14	11	14	14
20	15	15	13	15
21	13	13	14	13
22	12	10	10	9
23	14	14	13	13
24	12	11	9	9
25	11	12	13	12
26	13	14	12	13
Mean	13.1	12.2	11.8	11.9
SE	0.4	0.4	0.5	0.5

Mean Respiratory Exchange Ratio min 7-10

Subject ID	Trial 1	Trial 2	Trial 3	Trial 4
Female Subjects				
1	0.95	0.93	0.91	0.90
2	0.96	1.03	1.02	1.03
3	0.90	0.92	0.96	0.91
4	1.06	1.08	1.10	1.08
5	0.93	0.97	0.99	0.98
6	0.97	0.93	0.96	0.91
7	1.02	1.00	0.98	0.99
8	0.93	0.94	1.00	1.01
9	1.00	0.94	0.95	1.03
10	1.02	0.93	0.94	0.94
11	0.97	1.01	1.04	1.01
12	0.91	1.00	0.91	0.93
13	0.95	0.89	0.94	0.90
14	0.88	0.93	0.90	0.93
Male Subjects				
15	0.94	0.96	0.94	0.89
16	0.99	0.93	0.94	0.98
17	0.99	0.93	0.95	0.95
18	0.97	1.02	1.00	0.99
19	0.98	0.96	0.96	0.99
20	1.01	1.03	1.02	1.00
21	1.00	1.00	0.98	0.94
22	1.05	1.00	0.99	1.01
23	1.00	1.02	0.98	0.95
24	0.96	0.93	0.97	0.93
25	0.93	0.99	0.98	0.99
26	0.95	0.96	0.96	0.97
Mean	0.97	0.97	0.97	0.97
SE	0.01	0.01	0.01	0.01

APPENDIX H

PILOT STUDY #1

DATA TABLES

Pilot Subject #1 (female) VO_2 (ml/kg/min) Data for Trials 1-4
~5 MET workload

Time (sec)	Trial 1	Trial 2	Trial 3	Trial 4
0	4.9	2.9	3.3	3.1
15	5.9	8.2	7.5	4.9
30	9.8	10.1	8.8	7.9
45	17.9	13.5	10.5	10.1
60	18.3	13.7	11.6	10.7
75	19.4	15.7	12.7	11.9
90	17.4	15.3	14.6	13.8
105	28.1	15.9	14.4	14.7
120	23.1	15.8	14.8	15.3
135	23.3	16.4	16.3	16.0
150	25.1	16.2	14.8	15.9
165	25.8	17.6	17.5	15.7
180	25.4	17.6	18.3	17.1
195	29.1	17.1	16.8	16.6
210	25.8	17.4	17.4	16.5
225	25.0	17.8	17.5	17.1
240	26.0	17.6	17.1	17.5
255	24.6	17.5	18.8	17.6
270	22.4	17.2	17.1	18.1
285	22.4	18.0	18.5	17.3
300	21.8	17.2	18.1	18.3
315	21.6	17.1	17.7	18.3
330	22.4	18.7	18.0	17.9
345	21.7	18.2	18.5	18.2
360	21.1	16.5	18.0	17.7
375	21.3	18.0	17.9	18.4
390	21.5	18.3	18.3	17.7
405	21.1	17.5	18.5	19.0
420	20.6	17.9	17.4	17.5
435	21.2	18.0	19.3	18.9
450	20.0	18.6	18.7	17.1
465	20.8	17.7	19.5	18.6
480	21.4	17.6	19.3	17.7
495	21.2	18.4	18.5	17.8
510	19.4	18.4	17.8	18.5
525	22.2	18.3	18.1	18.8
540	20.9	19.2	19.6	18.6
555		17.6	18.5	18.3
570			19.6	18.3
585			17.5	
600			19.1	
Mean VO_2 min 7-10	20.9	18.2	18.7	18.2

Pilot Subject #2 (male) VO_2 (ml/kg/min) Data for Trials 1-4
~5 MET workload

Time (sec)	Trial 1	Trial 2	Trial 3	Trial 4
0	4.0	4.0	4.2	3.8
15	5.6	7.5	5.3	6.5
30	5.5	9.5	10.1	11.3
45	8.3	11.5	9.7	10.8
60	11.3	12.0	9.4	14.7
75	18.4	13.5	17.8	16.1
90	20.6	15.0	14.4	17.3
105	23.6	17.4	18.1	18.2
120	22.3	16.3	17.2	15.6
135	22.9	14.9	19.1	18.3
150	21.8	15.5	17.1	15.8
165	21.3	17.2	18.9	17.0
180	23.4	17.0	18.3	19.1
195	22.5	17.9	17.7	16.0
210	20.2	17.8	19.2	16.7
225	21.8	15.8	17.2	18.5
240	20.2	17.8	18.4	16.9
255	22.2	17.0	17.6	18.7
270	21.7	18.0	17.3	16.3
285	20.0	16.7	18.0	17.6
300	20.1	16.0	18.9	15.8
315	21.2	16.4	15.9	17.3
330	20.8	18.1	18.9	17.2
345	18.0	15.8	16.5	18.4
360	21.2	16.8	18.3	16.6
375	20.2	18.2	19.0	18.6
390	19.0	17.2	17.3	17.3
405	20.0	18.1	18.9	18.3
420	19.5	18.7	16.0	16.6
435	19.0	15.9	18.0	18.3
450	21.4	16.9	17.9	18.1
465	20.1	16.0	17.4	17.1
480	18.7	18.9	17.5	18.0
495	20.7	17.4	18.7	16.7
510	20.3	16.5	17.2	17.3
525	21.1	18.0	17.4	17.5
540	21.1	17.9	17.4	18.5
555	19.1	15.6	18.1	18.2
570	21.1	17.1	18.2	16.8
585	21.3	17.5	18.0	17.9
600	18.8	17.4	18.9	
Mean VO_2 min 7-10	20.2	17.2	17.7	17.6

Pilot Subject #1 (female) Heart Rate (bt/min) Data for Trials 1-4 & Max
~5 MET workload

Time (min)	Trial 1	Trial 2	Trial 3	Trial 4
0	87	64	79	88
1	160	116	141	130
2	171	130	146	136
3	171	143	156	140
4	169	153	158	142
5	168	160	160	146
6	172	158	162	151
7	170	158	162	154
8	171	160	165	150
9	171	164	167	158
10	171	164	167	155
Mean HR min 7-10	171	162	165	154

Time (min)	Max
0	76
1	110
2	103
3	99
4	115
5	125
6	136
7	158
8	160
9	167
10	176
11	179
12	183
13	183
14	189

Pilot Subject #2 (male) Heart Rate (bt/min) Data for Trials 1-4 & Max
~5 MET workload

Time (min)	Trial 1	Trial 2	Trial 3	Trial 4
0	64	59	79	60
1	110	99	104	95
2	121	95	103	102
3	117	93	107	103
4	114	97	106	103
5	115	96	106	98
6	115	98	105	96
7	115	93	106	100
8	117	101	105	103
9	116	102	109	105
10	120	101	107	105
Mean HR min 7-10	117	99	107	103

Time (min)	Max
0	70
1.5	89
3	91
4.5	105
6	116
7.5	134
9	156
10	

APPENDIX I

PILOT STUDY #2

DATA TABLES

Pilot Subject Summary Data

Subject ID	Age	Sex	Height (cm)	Weight (kg)	Workload METS	Upper Arm Girth (cm)	Tricep Skinfold (mm)
P1	22	M	185.5	76.7	5.1	30.5	3.5
P2	19	M	170.0	64.4	5.2	29.0	15.8
P3	26	M	183.0	79.5	4.9	31.5	10.2
P4	25	M	191.0	95.3	5.4	34.2	15.0
P5	19	M	155.0	53.5	5.1	29.0	5.2
P6	22	M	173.5	67.3	4.9	29.0	7.0
P7	22	M	183.0	96.4	5.3	32.5	18.0
P8	27	M	175.5	74.7	5.4	34.5	5.4
P9	25	M	175.0	84.5	5.4	35.0	13.0
P10	28	M	173.0	78.8	4.9	36.0	4.4
P11	19	M	172.0	68.2	4.9	29.0	7.0
Mean	23.1		176.0	76.3	5.1	31.8	9.5
SD	3.1		9.6	12.9	0.2	2.7	5.1
P12	26	F	158.0	53.3	3.1	27.0	17.5
P13	23	F	169.5	69.0	2.9	29.5	18.0
P14	32	F	157.5	68.8	2.9	30.0	21.4
P15	32	F	160.0	62.1	3.1	31.0	19.0
P16	25	F	174.0	64.8	3.1	25.0	12.2
P17	23	F	164.0	51.7	3.2	23.5	14.2
P18	23	F	163.0	62.2	3.2	27.0	16.8
P19	30	F	171.0	54.2	3.1	22.5	9.4
P20	28	F	160.0	65.9	3.0	29.0	19.0
P21	22	F	164.0	65.4	3.1	29.0	19.6
	26.3		164.1	61.7	3.1	27.4	16.7
	3.8		5.7	6.4	0.1	2.9	3.7

Pilot Subject Heart Rate Data (bpm) Submax Trials 1 & 2 for Rest and Minutes 1-10

Subject	Rest	1	2	3	4	5	6	7	8	9	10	Mean HR	RPE min 9
P1	68	104	109	109	111	109	109	107	116	119	120	114	
	79	102	112	117	113	112	114	112	118	116	113	115	8
P2	64	124	142	142	136	144	140	142	140	130	142	139	
	63	122	135	131	129	130	128	126	126	133	129	128	13
P3	71	96	105	103	109	112	113	112	112	111	103	110	
	82	114	112	112	112	109	110	114	127	119	119	118	11
P4	74	95	111	115	118	123	122	122	125	123	122	123	
	59	93	108	110	113	115	116	116	116	140	139	125	13
P5	86	120	134	139	142	147	150	156	163	167	165	160	
	77	132	143	144	140	144	150	149	153	160	152	153	12
P6	80	117	124	126	130	134	127	133	140	136	130	133	
	87	109	116	119	116	117	116	121	128	121	135	124	12
P7	75	120	133	140	142	145	154	152	151	152	155	152	
	93	124	128	134	142	136	146	147	147	147	155	148	9
P8	79	93	93	100	93	97	93	95	103	100	102	99	
	79	103	135	127	121	114	118	118	121	126	124	121	12
P9	66	114	124	128	132	131	138	132	140	140	139	137	
	71	104	109	112	114	112	114	115	117	119	119	117	9
P10	50	96	95	95	102	100	93	93	98	100	94	96	
	53	109	116	114	118	111	114	111	118	117	121	116	11
P11	64	110	121	117	114	115	115	115	117	116	120	116	
	74	99	95	93	97	96	98	93	101	102	101	99	12
P12	104	149	161	159	162	169	169					169	
	105	128	135	136	137	140	143	134	134	152	148	142	12
P13													
	68	90	103	101	101	104	107	101	111	108	106	107	10
P14	65	110	121	121	123	124	127	124	123	129	121	125	
	70	107	118	119	118	120	120	121	122	125	127	123	11
P15													
	76	106	92	107	111	113	109	116	120	119	116	116	8

Subject	Rest	1	2	3	4	5	6	7	8	9	10	Mean HR	RPE min 9
P16	68	110	105	105	106	104	112	122	113	107	103	111	
	68	93	92	95	94	100	91	105	99	102	100	100	11
P17	75	110	110	115	113	112	118	122	126	130	124	124	
	94	112	115	118	122	125	132	127	132	136	132	132	13
P18	84	106	115	123	126	129	131	131	130	127	130	130	
	66	101	108	111	118	114	119	122	121	118	120	120	9
P19	79	100	109	103	106	106	98	112	110	102	96	104	
	71	82	97	91	94	93	93	100	94	96	101	97	10
P20													
	81	110	108	109	109	103	105	109	121	114	111	112	11
P21	76	100	108	103	91	100	104	101	103	108	105	104	
	69	108	115	119	113	112	117	116	120	117	121	119	10

Pilot Subjects (Peak Test Data)

Subject ID	Number of Plates	Peak METS (Kayak Setting)	Total Time min	Max HR	Pred Max HR
P1	6	12.6	10.5	183	198
P2	5	9.8	7.7	178	201
P3	6	13.1	10.3	194	194
P4	7	11.6	8.3	160	195
P5	5	12.9	9.0	192	201
P6	5	12.8	8.8	190	198
P7	7	11.8	9.4	192	198
P8	5	11.1	9.5	177	193
P9	7	13.4	8.0	183	195
P10	6	9.5	7.8	163	192
P11	5	12.1	9.0	156	201
Mean	5.8	11.9	8.9	178.9	196.9
SD	0.9	1.3	1.0	13.7	3.1
P12	4	6.8	5.7	184	194
P13	4	13.1	13.0	189	197
P14	4	6.0	5.0	152	188
P15	3	7.7	8.5	163	188
P16	4	7.0	5.0	156	195
P17	4	7.0	4.5	163	197
P18	5	8.2	5.5	160	197
P19	5	10.7	5.0	158	190
P20	5	11.4	9.7	174	192
P21	5	9.6	7.8	170	198
Mean	4.3	8.8	7.0	166.9	193.6
SD	0.7	2.3	2.8	12.2	3.8

APPENDIX J

STATISTICAL TABLES

RESEARCH HYPOTHESIS

H_{01}: There is no difference in relative oxygen consumption, VO_2 (ml/kg), summed over the first 6 minutes of exercise, at a constant submaximal workload, on the StairMaster® 2650UE, across a subject's first four trials.

ANOVA Table for Oxygen Consumption summed over minutes 1-6

VO_2 (ml/kg)

Source	DF	SS	MS	F	P	
Subject	25	28992.6	1159.7	48.11	<0.001	
Trial	3	3856.8	1285.6	53.33	<0.001	*
Error	75	1807.9	24.1			
Total	103	34657.3				

* Significant differences were found across the four trials.

Tukey Analysis

~q(4,75)		HSD		T1	T2	T3	T4
3.73	0.963	3.59	Means	110.31	99.87	96.27	94.67
		T1	110.31	0			
		T2	99.87	10.44	0		
		T3	96.27	14.04	3.60	0	
		T4	94.67	15.64	5.20	1.60	0

Differences in means that are less than Tukey's HSD value (indicated by boxed numbers) are insignificant at an alpha level of 0.05.

RESEARCH HYPOTHESIS

H_{02}: There is no difference in the mean rate of oxygen consumption, VO_2 (ml/kg/min), over minutes seven through ten, at a constant submaximal workload, on the StairMaster® 2650UE, across a subject's first four trials.

ANOVA Table for Mean Rate of Oxygen Consumption (min 7-10)

VO_2 (ml/kg/min)

Source	DF	SS	MS	F	P	
Subject	25	1160	46.4	61.73	<0.001	
Trial	3	59.832	19.944	26.54	<0.001	*
Error	75	56.371	0.752			
Total	103	1276.2				

* Significant differences were found across the four trials.

Tukey Analysis

~q(4,75)		HSD		T1	T2	T3	T4
3.73	0.170	0.634	Means	19.76	18.51	18.01	17.81
		T1	19.76	0			
		T2	18.51	1.25	0		
		T3	18.01	1.75	0.50	0	
		T4	17.81	1.95	0.70	0.20	0

Differences in means that are less than Tukey's HSD value (indicated by boxed numbers) are insignificant at an alpha level of 0.05.

RESEARCH HYPOTHESIS

H_{03}: There is no difference in mean heart rate (bt/min) over minutes seven through ten, at a constant submaximal workload, on the StairMaster® 2650UE, across a subject's first four trials.

ANOVA Table for Mean Heart Rate (min 7-10)

HR (bt/min)

Source	DF	SS	MS	F	P	
Subject	25	23358.5	934.34	15.48	<0.001	
Trial	3	2529.92	843.31	13.97	<0.001	*
Error	75	4528.08	60.37			
Total	103	30416.5				

* Significant differences were found across the four trials.

Tukey Analysis

~q(4,75)		HSD		T1	T2	T3	T4
3.73	1.524	5.68	Means	139.42	129.88	129.62	126.15
		T1	139.42	0			
		T2	129.88	9.54	0		
		T3	129.62	9.80	0.26	0	
		T4	126.15	13.27	3.73	3.47	0

Significant differences were found across the four trials.

Differences in means that are less than Tukey's HSD value (indicated by boxed numbers) are insignificant at an alpha level of 0.05.

RESEARCH HYPOTHESIS

H_{04}: There is no difference in mean ventilation, V_E (l/min), over minutes seven through ten, at a constant submaximal workload, on the StairMaster® 2650UE, across a subject's first four trials.

ANOVA Table for Mean Ventilation (min 7-10)

V_E (L/min)

Source	DF	SS	MS	F	P	
Subject	25	16527	661.08	83.57	<0.001	
Trial	3	447.03	149.01	18.84	<0.001	*
Error	75	593.29	7.91			
Total	103	17567.3				

* Significant differences were found across the four trials.

Tukey Analysis

~q(4,75)		HSD		T1	T2	T3	T4
3.73	0.552	2.06	Means	41.60	37.85	37.14	36.10
		T1	41.60	0			
		T2	37.85	3.75	0		
		T3	37.14	4.46	0.71	0	
		T4	36.10	5.49	1.74	1.03	0

Differences in means that are less than Tukey's HSD value (indicated by boxed numbers) are insignificant at an alpha level of 0.05.

RESEARCH HYPOTHESIS

H_{05}: There is no difference in rate of perceived exertion at minute nine, at a constant submaximal workload, on the StairMaster® 2650UE, across a subject's first four trials.

ANOVA Table for Rating of Perceived Exertion (min 9)

RPE

Source	DF	SS	MS	F	P	
Subject	25	486.74	19.47	20.35	<0.001	
Trial	3	25.49	8.497	8.88	<0.001	*
Error	75	71.76	0.957			
Total	103	583.99				

* Significant differences were found across the four trials.

Tukey Analysis

~q(4,75)		HSD		T1	T2	T3	T4
3.73	0.192	0.72	Means	13.08	12.23	11.85	11.89
		T1	13.08	0			
		T2	12.23	0.85	0		
		T3	11.85	1.23	0.39	0	
		T4	11.89	1.19	0.35	0.04	0

Differences in means that are less than Tukey's HSD value (indicated by boxed numbers) are insignificant at an alpha level of 0.05.

RESEARCH HYPOTHESIS

H_{06}: There is no difference in mean respiratory exchange ratio over the minutes seven through ten, at a constant submaximal workload, on the StairMaster® 2650UE, across a subject's first four trials.

ANOVA Table for Respiratory Exchange Ratio (min 7-10)

RER

Source	DF	SS	MS	F	P
Subject	25	0.14305	0.00572	6.99	<0.001
Trial	3	0.00034	0.00011	0.14	0.936 *
Error	75	0.06141	0.00082		
Total	103	0.20480			

* No significant differences were found across the four trials.

Tukey Analysis

~q(4,75)		HSD			T1	T2	T3	T4
3.73	0.006	0.021	Means		0.970	0.970	0.972	0.967
		T1		0.970	0			
		T2		0.970	0.000	0		
		T3		0.972	0.002	0.002	0	
		T4		0.967	0.003	0.003	0.005	0

Differences in means that are less than Tukey's HSD value (indicated by boxed numbers) are insignificant at an alpha level of 0.05.

APPENDIX K

RAW DATA

Heart Rate Data (at rest and minutes 1 through 10 of exercise)

Subject ID	Rest	1	2	3	4	5	6	7	8	9	10
1	91	129	147	130	149	144	149	149	149	158	160
	79	114	118	115	114	112	115	114	125	121	124
	87	114	117	121	120	123	128	127	127	121	127
	79	117	105	104	107	107	111	115	113	115	113
2	76	125	126	129	123	127	135	133	139	136	135
	74	106	117	117	113	114	119	121	121	120	123
	87	114	110	126	125	124	130	129	134	135	133
	100	114	123	124	122	132	135	133	132	136	136
3	66	149	149	146	150	153	153	156	155	153	154
	62	132	146	142	139	143	138	156	153	139	152
	67	129	129	134	134	128	139	139	138	146	146
	68	115	126	121	128	128	125	123	134	126	135
4	86	115	109	124	118	115	120	114	124	122	127
	81	115	128	126	124	126	132	128	124	133	132
	93	146	126	125	120	127	129	127	130	130	129
	104	121	115	123	117	115	121	130	126	134	129
6	78	122	113	116	115	123	119	125	121	120	124
	80	105	107	109	113	117	123	123	125	123	128
	90	140	121	127	133	134	134	143	140	139	147
	80	99	105	107	109	106	106	111	115	115	115
7	80	113	114	113	118	116	111	111	117	112	109
	78	96	106	99	97	98	99	104	100	103	103
	78	99	105	102	99	102	104	99	103	103	103
	79	106	103	107	106	103	107	106	106	103	112
8	64	120	126	129	133	132	127	136	135	135	133
	67	112	119	121	119	117	121	121	127	127	126
	75	116	115	114	116	116	117	121	120	121	120
	69	107	112	114	115	116	119	115	111	115	109
9	77	96	112	96	96	98	101	97	99	99	100
	69	101	100	104	96	101	103	98	96	104	106
	91	103	116	112	110	108	112	109	107	115	117
	71	96	99	99	89	105	97	96	100	95	101
10	84	139	158	165	167	165	170	174	174	174	170
	68	142	142	147	156	152	146	147	147	152	143
	75	144	144	142	139	142	144	142	142	152	147
	78	134	132	129	130	132	134	129	139	139	136

Subject ID	Rest	1	2	3	4	5	6	7	8	9	10
12	74	140	117	105	110	116	115	121	127	127	132
	72	100	100	105	106	107	101	112	106	107	101
	75	101	101	99	103	101	100	101	101	101	96
	68	101	99	96	94	94	90	96	96	100	94
13	82	135	140	142	139	146	146	147	152	160	160
	101	128	135	136	142	142	142	142	147	146	147
	90	123	136	130	133	138	140	139	142	142	144
	88	125	130	135	147	143	153	147	153	155	156
15	59	121	126	119	129	132	128	132	132	132	134
	56	96	104	97	109	106	107	107	119	119	112
	67	100	103	99	109	110	110	112	124	121	120
	73	106	108	107	115	115	112	125	126	129	123
16	97	115	119	124	122	127	130	127	130	134	134
	88	125	138	144	142	143	144	146	149	150	149
	75	109	115	115	108	118	120	122	127	128	129
	67	102	110	109	110	112	115	118	119	120	121
18	77	110	115	116	121	123	123	121	132	126	125
	70	104	109	111	111	115	115	117	118	119	115
	74	107	112	114	119	120	123	121	129	123	130
	67	107	107	121	117	118	123	123	129	127	130
19	78	132	139	140	150	153	156	160	165	167	165
	84	123	127	134	132	142	138	144	152	149	149
	89	115	125	123	124	129	133	134	138	143	143
	80	121	124	128	132	132	133	142	144	146	143
20	70	112	123	119	121	123	123	128	129	128	
	70	107	116	115	115	123	121	119	125	128	128
	70	99	109	112	109	109	111	111	117	117	119
	82	99	112	115	114	115	120	119	123	125	124
21	79	138	144	149	152	152	152	155	156	161	163
	81	139	143	146	149	153	150	152	160	156	160
	99	117	146	153	155	153	154	155	156	157	157
	91	139	152	156	156	156	156	160	163	163	156
22	79	109	109	130	132	127	132	132	142	146	144
	76	106	115	110	121	125	126	124	134	132	134
	82	110	127	127	127	132	134	134	132	134	134
	75	99	107	106	114	114	114	121	118	125	124

Subject ID	Rest	1	2	3	4	5	6	7	8	9	10
23	72	149	147	158	165	165	165	167	169	172	179
	62	136	140	149	150	155	155	155	158	160	161
	79	128	132	142	143	147	152	150	149	152	152
	82	117	124	130	132	133	135	138	136	143	142
24	67	121	134	139	140	147	150	152	150	155	160
	67	114	123	121	129	134	143	149	152	153	163
	74	106	112	127	135	139	144	147	150	156	155
	61	112	120	127	129	139	139	142	144	147	152
25	68	100	103	101	109	113	116	115	119	121	120
	63	95	98	104	101	108	110	111	119	120	114
	68	92	89	101	100	103	109	109	115	123	119
	60	82	94	93	99	103	106	99	108	104	109
26	88	125	139	142	140	136	143	146	146	147	152
	81	119	121	127	124	129	132	134	135	134	135
	74	114	117	126	127	126	133	130	129	134	138
	65	113	115	117	125	123	127	125	128	132	132
27	80	130	134	130	130	130	134	142	136	144	144
	68	118	132	126	121	132	129	129	132	130	
	76	114	111	110	111	119	125	126	125	126	119
	71	119	129	127	126	129	132	130	129	133	132
28	90	142	147	160	160	161	163	160	165	163	167
	74	129	146	147	150	152	128	125			
	78	126	124	130	134	135	140	143	144	142	136
	58	112	115	117	125	127	136	144	142	142	142
29	52	99	107	108	112	113	115	114	112	117	119
	61	109	114	117	117	119	123	119	119	125	121
	66	96	110	109	113	110	112	106	110	112	110
	70	98	103	105	108	111	110	108	111	114	109
30	75	132	136	132	135	138	142	138	142	144	142
	66	116	127	123	117	126	125	124	132	134	132
	68	109	125	127	133	132	135	135	135	138	138
	65	122	121	127	125	127	129	127	132	132	134

VITA

Christopher E. Callaghan was born in 1969 and grew up in Wilmington, Delaware. In 1987, he graduated from Concord High School and began studies at Virginia Tech in the engineering department. While he was in Blacksburg, in the fall of 1988, he began studying martial arts under Dr. Ed Hampton. In 1991, he graduated from the aerospace engineering department with a Bachelor of Science and a minor in mathematics. In the fall, he entered the Master of Business Administration program at Virginia Tech. That winter, he began teaching the beginning kung fu class at Dr. Hampton's school. The exposure to martial arts led him to take Dr. Rankin's exercise physiology course in the fall of 1992, which in turn led to his interest in the field of corporate fitness. After some research on the evaluation of corporate fitness programs, he graduated from the MBA program in May of 1993. Once again, in the fall he began studies at Virginia Tech, this time working towards a masters degree in the field of exercise physiology with a concentration in adult fitness and cardiac rehabilitation. His plans are to graduate in May of 1996 and enter the doctoral program in clinical exercise physiology at Virginia Tech.